UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

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OFFICE OF CHEMICAL SAFETY
AND POLLUTION PREVENTION

MEMORANDUM

SUBJECT: Assessment of the Benefits of Atrazine and the Impacts of Potential Mitigation for Field Corn, Sweet Corn, Sorghum, and Sugarcane; PC Code (080803)

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SUMMARY

The Environmental Protection Agency (EPA or the Agency) is reconsidering a portion of the Atrazine Registration Review Interim Decision issued in September 2020 related to potential ecological off field risks to aquatic plant communities associated with the agricultural uses of atrazine. This memorandum summarizes information from past assessments of the benefits of atrazine, considers whether those benefits have changed, and assesses impacts of potential risk mitigation for atrazine in field corn, sweet corn, sorghum, and sugarcane, the four major agricultural use sites for atrazine.

Atrazine is widely used in field corn, sweet corn, sorghum, and sugarcane – over half of all acres planted of each of these crops are treated with atrazine each year. Atrazine is an important herbicide in these crops because it is economical, has a flexible use pattern, long residual herbicidal activity and is effective against a broad spectrum of weeds. Atrazine is an important tool in herbicide resistance management, both in controlling weeds resistant to other herbicides and maintaining the effectiveness of other herbicides to control weeds.

The benefits of atrazine are high in these four crops, increasing grower net operating revenue by up to $30 per acre in field corn, up to $52 per acre in sweet corn, and up to $16 per acre in sorghum compared to the next best alternative weed control options. Atrazine is especially beneficial for Southern growers, who may not have efficacious alternatives to atrazine for regional weed pressures. In sugarcane, atrazine increases grower net operating revenue by up to $13 per acre compared to the next best alternative weed control options. These benefits are estimated as the impact on growers if atrazine were not available – without atrazine, growers would face up to a 61% decrease in net operating revenue in field corn, up to complete net revenue loss in sweet corn, up to a 67% decrease in net operating revenue in sorghum, and up to a 17% decrease in net operating revenue in sugarcane.

The Agency is considering mitigation measures to reduce risks due to runoff from the use of atrazine, including limiting when and how atrazine can be applied, reducing maximum use rates, and requiring the adoption of engineering and agronomic practices that reduce runoff. The Agency could require growers adopt some or all of these mitigation measures, or the Agency could require a “pick-list” where growers can select some combination of runoff mitigation measures to reduce runoff to continue using atrazine. These practices could include structural changes to the field, such as terraces or vegetated filter strips, or these could be changes to grower agronomic practices, such as using lower rates of atrazine or growing cover crops. The number of practices required for growers to adopt could be determined by crop, region, soil erodibility, watershed, and the annual atrazine rate used. The impact on growers of complying with individual potential mitigation measures are:

- Application rate reductions would cause growers who currently use higher than a new maximum rate to reduce their rate or seek alternatives to atrazine. Lower rates could reduce weed control which would likely complicate herbicide resistance management by increasing selection pressure for atrazine-resistant weeds and making atrazine less effective as a tool to control weeds that are resistant to other herbicides. Growers could

compensate by using additional herbicides or replacing atrazine entirely. The larger the rate reduction the more impactful the restriction will be for growers, thereby making it more difficult for growers to find a way to continue to use atrazine effectively. Further, the larger the rate reductions the more growers will have to adjust their atrazine use in response. For example, reducing maximum annual atrazine rates to one-pound per-acre in field corn would impact 30% of current acres treated nationally, and 60% of current acres treated in the Southern U.S. The magnitude of impacts vary both between crops and between regions within crops. Regionally, rate reductions are likely to be less feasible for growers of field corn and sweet corn in the Southern U.S. and for sugarcane growers in Florida, who apply at higher rates.

- Prohibiting aerial applications of atrazine when soil is saturated, and restricting applications of atrazine prior to forecasted rainfall would together limit the ability of growers to use atrazine from the start of forecasted rain until the ground is no longer saturated. The limitation on application prior to forecasted rainfall could be particularly impactful because it may prevent timely atrazine applications, even if precipitation does not actually occur. The longer the restricted interval prior to forecasted rainfall, the more difficult it would be for growers to use atrazine. If weed control is necessary in that window of time, growers would need to use alternatives to atrazine, facing impacts as described above, or else face yield losses. BEAD notes that many growers would not apply before heavy rainfall which is likely to produce runoff, as this could result in poor weed control. If applications of atrazine are not restricted prior to rainfall which is unlikely to produce runoff (light rain), then the rainfall restriction is less impactful.
- Eliminating preemergence applications eliminates a common application timing for atrazine. Atrazine is frequently used prior to crop emergence in sorghum and field corn production, and to a lesser extent in sweet corn. Some growers who currently use atrazine prior to crop emergence can move these applications after crop emergence, but may face cost increases to replace weed control prior to crop emergence. Growers who use atrazine twice a year would need to replace atrazine and thus may face cost increases or a reduction in weed control.
- Requiring soil incorporation of atrazine instead of surface-applied atrazine may have low impacts on growers depending on their atrazine tank-mix partners and application timing. Soil incorporation is a form of tillage and is only viable for preplant applications because it would displace seeds after planting or damage the crop after emergence. This means that soil incorporation is not compatible with other mitigation measures such as eliminating preemergence applications or requiring no-till or conservation tillage systems. Soil incorporation also has costs associated with tillage and additional application costs if tank-mix partners cannot be soil incorporated.
- Requiring no-tillage or reduced-tillage production would impose high costs on producers of sweet corn or sugarcane production because tillage is important for weed control in sugarcane, and is unlikely to be infeasible in sweet corn because the crop has low seedling vigor and does not establish well in no- or reduced-till fields. For corn and sorghum growers, switching to no-till or reduced tillage systems would likely require investment in new equipment or retrofitting existing equipment for managing the crop

under high-plant residue conditions. Also, as no-till and reduced tillage systems rely heavily on herbicides for early-season weed control, these systems may increase the impact to the grower of other mitigation measures such as reducing application rates or prohibiting preemergence applications.

- Requiring cover crops would raise production costs since it involves establishing and removing a crop that produces little or no revenue. Cover crops can be incorporated into corn and sorghum production systems that have adequate natural rainfall or are irrigated (e.g., the Corn Belt and Southeast) but are less feasible in dryland areas with low rainfall (e.g., the Plains states). Cover crops are not feasible for use with sweet corn due to the low seedling vigor of sweet corn in fields with cover crop residues, similar to no-till and reduced-till systems, and are not feasible for use with sugarcane due to the perennial production system.
- Requiring irrigation water management requires managerial expertise and may require purchasing specialized equipment, which may be costly. Growers who do not irrigate cannot conduct irrigation water management.
- The impact of requiring vegetative filter strips (VFS), field borders, grassed waterways, contour buffer strips and contour terracing, and grass ditch banks is dependent on the size and topography of the field and on the size of the required buffer. As buffers take land out of production, BEAD anticipates that growers could face substantial loss of cropped land and thus loss of revenue. Growers with smaller fields and growers of crops that are typically grown in small fields, particularly sweet corn and sugarcane, will lose a larger portion of their field to buffers compared to growers with large fields. These measures require capital investments in land modification. Establishment costs for VFS, for example, range from $165-$927 per acre of VFS and maintenance costs range from $40-$240 annually per acre of VFS. Contour terracing may be more expensive than other kinds of buffers, as they require the creation of semi-permanent ridges. Contour buffer strips and terracing are not feasible where crops are produced on flat land and are not applicable to sugarcane production.
- Requiring contour farming or strip cropping will impose a variable burden depending on field slope. These practices may be burdensome but feasible for production of annual crops on sloped fields, requiring substantial managerial effort and purchasing specialized equipment. However, contour farming and strip cropping are likely impossible on sugarcane or other crops produced on flat fields.

Compared to specifying a fixed set of mitigations, which would likely represent an effective cancelation of atrazine for many users, a pick-list of mitigation measures gives growers flexibility, allowing growers to select the least burdensome method to achieve the required number of practices necessary to use atrazine. The impacts of complying with a required pick-list depend on the grower's current agronomic production practices, region of the country, the watershed their field is located in, and whether the grower is already undertaking any of the measures described on the mitigation pick-list. Additionally, managerial effort is higher with a pick-list than a specific list of mandatory requirements. Some runoff reduction practices preclude adoption of other practices. How burdensome this pick-list is for growers depends on how many runoff reduction practices are required for growers to use atrazine. It may be harder for sweet corn and sugarcane growers to adopt multiple practices from the pick-list compared to field corn and sorghum growers. The potential mitigations may also be more burdensome for small and lower-income farmers. Growers for whom achieving the required number of required practices is too burdensome would have to replace atrazine with other herbicides and would lose the benefits of atrazine as described previously.

INTRODUCTION

Atrazine is a chlorinated triazine herbicide, a class of herbicides that also includes the herbicides simazine and propazine. Atrazine is a Photosystem II (PS II) Inhibitor and is classified as a Weed Science Society of America (WSSA) Group 5 herbicide. Atrazine is a systemic herbicide with good residual activity that is widely used to selectively control annual grasses and broadleaf weeds before they emerge. Atrazine is registered for use in agricultural crops, including field corn, sweet corn, sorghum, sugarcane, fallow periods in wheat crop rotations, macadamia nuts, and guava, as well as non-agricultural uses such as nursery/ornamental, turf, and rights-of-way excluding roadsides.

The Agency most recently re-evaluated atrazine in 2019 in a Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) Interim Registration Review Decision (US EPA, 2020), where mitigations were adopted to address risks to human health and the environment. The Agency adopted further mitigation measures for atrazine related to the ongoing evaluation of the potential effect of atrazine on endangered species in support of the biological evaluation, as required by the Endangered Species Act (ESA) (US EPA, 2021).

On October 30, 2020, Petitioners challenged the EPA's issuance of the atrazine interim decision (ID) by filing a Petition for Review in the Ninth Circuit Court of Appeals. The Petition alleges that EPA violated its duties under FIFRA as it relates to the atrazine ID based on a lack of substantial supporting evidence. In a partial response to the Petition, EPA is reevaluating the decision to determine whether additional mitigation to reduce exposure to non-target organisms is warranted, specifically exposure due to runoff from fields treated with atrazine where monitoring and/or modeling indicate that the concentration of atrazine exceeds the level of concern (CE-LOC) (3.4 µg/L), taking into account the impacts of possible mitigation.

The Agency is considering several mitigation options to reduce the potential for exposure of aquatic plant communities to atrazine via applications in agricultural use patterns. Broadly speaking, options can be categorized as 'structural,' which are land modifications that typically involve high initial costs and are semi-permanent, or as 'agronomic,' which are practices that can be adopted each year or even within a season. This memo summarizes past assessments of the benefits of atrazine and briefly reassesses the current benefits of atrazine. This document also assesses the impacts of potential mitigations on growers. This assessment focuses on the four major agricultural use sites for atrazine: field corn, sweet corn, sorghum, and sugarcane.

METHODOLOGY

This document updates existing EPA assessments of the usage and benefits of atrazine. BEAD previously assessed atrazine in 2019 as part of the atrazine registration review process. BEAD identified field corn, sweet corn, sorghum, and sugarcane as the four main agricultural use sites for atrazine. The benefits of the use of atrazine were assessed by region of the country.

To determine whether the benefits of atrazine have substantially changed since the publication of the 2019 assessments, BEAD provides updated atrazine usage data, including application rates and application timings, for field corn, sweet corn, and sorghum using market research data. More recent data on pesticide usage in sugarcane have not been collected. BEAD also reviews available extension literature to assess any changes in the agronomic role of atrazine or in the alternatives available for field corn, sweet corn, sorghum, and sugarcane. BEAD assesses the benefits of atrazine by comparing expected grower outcomes with the use of atrazine to outcomes with the use of alternative weed control measures.

Based on the benefits of atrazine, BEAD assesses the impacts of potential mitigations. BEAD qualitatively evaluates the impacts of each mitigation in terms of how difficult the mitigation is for growers to adopt. BEAD assesses the viability of the adoption of each mitigation, including identifying crop and regional differences in the viability of adoption of each practice. When relevant, BEAD considers the implications of each mitigation for herbicide resistance management and provides any implications for environmental justice. BEAD then considers the viability of using a pick-list to give growers flexibility in choosing a set of mitigations to reduce runoff.

USAGE AND BENEFITS

According to BEAD assessments in 2019 (McFarley and Lee, 2019; Tindall and Kells, 2019; Tindall and Sells, 2019; Tindall and Smearman, 2019), most atrazine is used in field corn, sweet corn, sorghum, and sugarcane, and the majority of the acreage of these crops grown annually is treated at least once with atrazine. Atrazine is also registered for use in guava, macadamia nuts, and wheat (fallow only), and non-agricultural use sites. The most recent available market research data also suggests field corn, sweet corn, sorghum, and sugarcane are the most important agricultural use sites for atrazine – over half of all acres grown of each of these crops are treated with atrazine annually (Kynetec, 2020b). BEAD qualitatively assesses the current benefits of atrazine in each use site.

<u>Field Corn</u>

Previous Assessment

<u>Previous Use and Usage</u>

BEAD previously assessed the benefits of atrazine to field corn growers in 2019 (Tindall and Smearman, 2019). This assessment assessed the benefits of atrazine at the national level, as well as specifically for three major field corn production regions: the Corn Belt (Illinois, Indiana, Iowa, Missouri, and Ohio), the Plains States (Colorado, Kansas, Nebraska, North Dakota, Oklahoma, South Dakota, and Texas), and the Southern Seaboard (Alabama, Delaware, Georgia, Maryland, North Carolina, South Carolina, and Virginia). BEAD determined in 2019 that these three regions would provide information about the benefits of atrazine in field corn that could be extrapolated to other major field corn use regions of the country, including the Northeast, Mid-South, and Eastern Uplands.

Based on market research data from 2013-2017, BEAD found that on average each year, about 62.3 million pounds of atrazine was used on about 53.3 million base acres of field corn (base acre is a physical acre treated with atrazine; it is counted once annually, no matter how many times that acre was treated with atrazine), equivalent to approximately 58% of all field corn acres (Tindall and Smearman, 2019). BEAD found that the highest usage of atrazine, in pounds applied and in acres treated, was in the Corn Belt – which is not surprising, as these states grow the most field corn. The states with the highest percentage of the field corn crop treated with atrazine were the Southern states, from Louisiana to Delaware. Annual application rates were higher in the Southern states (over one pound per acre on average) than in the Corn Belt or Plains states (less than one pound per acre on average). BEAD anticipated that that farmers in the Northeast region will likely be impacted similarly as those in the Corn Belt region, and that farmers in Mid-South and Eastern Uplands regions would experience similar impacts as those in the Southern Seaboard.

Atrazine was the second most used herbicide in field corn after glyphosate in terms of total acres treated (total acres are applications to a physical acre; multiple applications to the same acre count as multiple treated acres) (Tindall and Smearman, 2019). Atrazine was used both before and after crop emergence, but most applications of atrazine made to field corn were made prior to crop emergence (60% of total acres treated). Seven percent of field corn acres treated with atrazine are treated both prior to and after crop emergence. Growers used atrazine to target both broadleaf weeds and grasses, including lambsquarters, velvetleaf, marestail, and pigweeds. Atrazine was frequently applied both on its own and as part of a tank-mix or premix. 99% of atrazine (in pounds) was applied via ground equipment.

Previous Benefits

In 2019, BEAD found that atrazine was an important herbicide in field corn, especially for field corn growers in the South where weed pressure is higher (Tindall and Smearman, 2019). Atrazine was economical, with a flexible use pattern, a long residual period, and good crop safety, and was effective against a broad spectrum of weeds. BEAD found that atrazine was an important herbicide for controlling glyphosate-resistant and difficult-to-control weeds, particularly when co-applied with a 4-Hydroxyphenylpyruvate dioxygenase (HPPD) inhibiting herbicide.

In the Corn Belt, prior to crop emergence, BEAD found that alternatives to atrazine included saflufenacil (Group 14) and a rescue treatment with 2,4-D (Group 4) (Tindall and Smearman, 2019). After crop emergence in the Corn Belt, alternatives to atrazine include tembotrione (Group 27) or a co-application of flumetsulam (Group 2), acetochlor (Group 15), and halosulfuron (Group 2). BEAD found that if Corn Belt growers used alternatives to atrazine, they could face increased herbicide costs of $8-$28 per acre (equivalent to a loss of between 4% and 13% of grower net operating revenue) (Tindall and Smearman, 2019). BEAD anticipated that farmers in the Northeast region would likely be impacted similarly to those in the Corn Belt.

In the Plains States, alternatives to atrazine prior to crop emergence included mesotrione (Group 27) alone or with saflufenacil (Group 14), while after crop emergence, atrazine could be replaced with a mix of mesotrione (Group 27) and primisulfuron (Group 2). BEAD found that alternatives to atrazine in the Plains States could increase herbicide control costs by $9 to $30 per acre (equivalent to a loss of up to 61% of grower net operating revenue). Additionally, BEAD was uncertain available alternatives were sufficient to replace atrazine for control of kochia, but noted that if Kochia control were reduced, growers would incur higher control costs or incur yield losses.

In the Southern Seaboard, alternatives to atrazine included simazine (another triazine, Group 5) or flumetsulam (Group 2) plus dimethenamid (Group 15) prior to crop emergence, while a mix of ametryn (Group 5) and linuron (Group 7) could replace atrazine after crop emergence. In the South, alternatives to atrazine could increase grower herbicide costs by $1 if growers are able to replace atrazine with simazine, and by up to $17 per acre if replacing atrazine with other alternatives (up to 16% loss in grower net operating revenue). Additionally, growers may require upgrades in equipment to do directed postemergence sprays due to phytotoxicity concerns. BEAD also found that in the absence of atrazine after crop emergence, growers in the South may be unable to replace atrazine for control of morningglory, and in the absence of atrazine may suffer substantial losses in yield and net operating revenue. BEAD anticipated that farmers in the Mid-South and Eastern Uplands regions would likely be impacted similarly as those in the Southern Seaboard.

New Information

Current Use and Usage

The most recent available usage information from 2015-2019 (Kynetec, 2020a) suggests that the use patterns for atrazine in field corn remains similar to the use patterns observed in BEAD's previous assessment. On average, about 63 million pounds of atrazine are applied annually to about 53 million acres of field corn (Table 1). Atrazine usage remains highest in the Corn Belt, where most corn is grown, but the percentage of the field corn crop treated with atrazine is still highest in the Southern states (exemplified below in Table 1 by Southern Seaboard).

Table 1: Atrazine Use in Field Corn by Region (2015-2019)

	National[1]	Corn Belt[2]	Plains States[3]	Southern Seaboard[4]
Total Pounds Applied Annually	62,900,000	30,200,000	18,200,000	3,900,000
Total Acres Treated[5]	67,200,000	31,500,000	21,200,000	3,100,000
Average Application Rate (lbs a.i./acre)	0.94	0.96	0.86	1.24
Base Acres Treated[5]	53,100,000	24,300,000	16,400,000	2,400,000
Average Annual Application Rate (lbs a.i./acre/year	1.18	1.24	1.11	1.65
Percent Crop Treated	59%	66%	60%	77%

Data from Kynetec (2020b).

[1] Includes Corn Belt states, Plains States, and Southern Seaboard states, as well as the rest of the United States.

[2] Illinois, Indiana, Iowa, Missouri, and Ohio.

[3] Colorado, Nebraska, North Dakota, South Dakota, Kansas, Oklahoma, and Texas.

[4] Alabama, Delaware, Georgia, Maryland, North Carolina, South Carolina, and Virginia.

[5] Total acres treated account for multiple applications per year. Base acres treated are acres treated at least once. Acres treated may be overestimated if two atrazine products are mixed together since data are tabulated at the product level.

Annual application rates in the Southern states are still higher than annual application rates in the Corn Belt or Plains States (Kynetec, 2020a). According to current usage information, 99% of atrazine applied to field corn is applied via ground applications; the remainder is applied aerially.

<u>Current Benefits</u>

In the three years since the previous assessment there have been important changes to the benefits picture. In 2019, BEAD identified simazine as the most likely alternative to atrazine prior to crop emergence in the Southern Seaboard. Recent comments from state Extension weed control specialists suggest that simazine is not a viable alternative to atrazine in field corn, as simazine does not have sufficient herbicidal activity on emerged weeds and provides poorer control of broadleaf weeds, the primary targets for atrazine (USDA OPMP, 2022). As simazine was the cheapest alternative to atrazine identified in 2019, without atrazine, growers would likely face increases in cost near the upper end of the range estimated in 2019.

Similarly, linuron was identified as an alternative to atrazine in the Southern Seaboard region in 2019. However, the dry flowable formulation of linuron was recently cancelled for use in field crops. Field corn growers would still have the option to use liquid formulations of linuron as an alternative to atrazine; however, prior to the cancellation of dry flowable linuron in field crops, the dry flowable formulation was the most commonly applied formulation of linuron in field corn. BEAD is unsure of whether linuron remains a viable alternative to atrazine in field corn. If linuron is no longer a viable alternative, BEAD expects Southern growers to face either higher control costs or worse pest control in the absence of atrazine than BEAD concluded in 2019.

According to recent Extension literature, weeds resistant to glyphosate, acetolactate synthase (ALS) inhibitors, HPPD inhibitors, and protoporphyrinogen oxidase (PPO) inhibitors, continue to be problematic in corn-growing regions. Atrazine applied alone or in tank mixes with other herbicides is recommended to control resistant biotypes of Palmer amaranth, waterhemp, and ragweeds resistant to other herbicide modes of action (Loux et al. 2020, Hartzler and Jha 2021, Mississippi State University Extension, 2021). BEAD's previous assessment identified that alternatives to atrazine may include saflufenacil (Group 14) and a rescue treatment with 2,4-D (Group 4) (Tindall and Smearman 2019). However, 2,4-D-resistant pigweeds have been identified in corn (Heap, 2021) and other crops like soybean and cotton which are commonly rotated with corn (Orlowski et al., 2022), which would reduce the effectiveness of 2,4-D rescue treatments as an alternative to atrazine in areas with resistant biotypes. Furthermore, resistance to PPO inhibitor herbicides (WSSA Group 14), like saflufenacil is spreading, further limiting the available alternatives to atrazine in field corn (Oliveria et al., 2021; University of Arkansas, 2022). Therefore, there are likely fewer viable alternatives to atrazine than in 2019.

Since BEAD's initial assessment, herbicide resistant weeds have continued to spread and new herbicide-resistance issues have emerged. Herbicide options for postemergence control of problematic broadleaf weeds like Palmer amaranth in soybean and cotton are currently limited to synthetic auxin herbicides (WSSA Group 4), specifically 2,4-D and dicamba, and glufosinate (WSSA Group 10) (Orlowski et al., 2022). However, resistance to 2,4-D, dicamba, and glufosinate in Palmer amaranth have emerged and are spreading, resulting in a lack of effective control options in these crops which are often rotated with corn. Multiple state agricultural Extension agencies recommend rotating fields infested with these multiple-herbicide resistant Palmer amaranth to corn, allowing growers to use atrazine, essentially the only remaining highly effective herbicide remaining for control of these weeds (Legleiter and Johnson 2013, Everman and York 2016; Devkota and Ferrell, 2019; Barber, 2020). Therefore, given the high level of weed resistance in Palmer amaranth in certain areas like Tennessee and Arkansas, atrazine is important not just for Palmer amaranth management in corn, but for Palmer amaranth management in entire rotational systems. As multiple-herbicide resistant Palmer amaranth is highly likely to continue to spread, the benefits of atrazine for control of this weed will likely expand with it.

Current usage is largely similar to that observed in BEAD's previous assessment and the spread of weed resistance, especially in problematic broadleaf weeds like Palmer amaranth and waterhemp, mean that the benefits of atrazine for control of these herbicide-resistance weeds have increased since the initial assessment. Further, new comments from USDA OPMP (2022) suggest that simazine, the cheapest alternative to atrazine identified in 2019 (Tindall and Smearman, 2019), is not a viable replacement for atrazine. BEAD therefore concludes that atrazine continues to be an extremely important herbicide for weed control in field corn, and the benefits of atrazine in field corn are likely larger than BEAD estimated in 2019, particularly for growers facing multiple-herbicide-resistant weeds, especially those in the Southern United States.

Sweet Corn

Previous Assessment

Previous Use and Usage

BEAD previously assessed the use, usage, and benefits of atrazine to sweet corn growers from 2013-2017 (Tindall and Kells, 2019) at the national level and for three production regions: the North Central / Northeastern region (Indiana, Illinois, Michigan, Minnesota, New Jersey, New York, Ohio, Pennsylvania, and Wisconsin), the Northwest (Idaho, Oregon, and Washington), and the Southeast (Alabama, Delaware, Florida, Georgia, Maryland, North Carolina, South Carolina, and Virginia). Sweet corn is also grown in California, but atrazine is rarely used in California sweet corn production.

BEAD found that 368,000 acres of sweet corn (approximately 70% of all sweet corn acres grown) were treated with 303,000 pounds of atrazine annually from 2013-2017 (Tindall and Kells, 2019). The majority of atrazine applied (54% of pounds applied) was used in the North Central / Northeastern region, which is also the largest producer of sweet corn by acreage (accounting 49% of all sweet corn acres). However, atrazine was used on a higher percentage of sweet corn acres in the Southeast and Northwest regions than in the North Central / Northeast.

Nationally, half of total sweet corn acres treated with atrazine were treated prior to crop emergence, and half were treated after crop emergence (Tindall and Kells, 2019). However, application timing differed by region – Atrazine was applied more often prior to crop emergence in the Northeast/North-Central region, while it was applied more often after crop emergence in the Northwest. Atrazine is frequently applied either prior to or after crop emergence in the Southeast. Nationally, 11% of sweet corn acres treated with atrazine were treated both prior to crop emergence and after crop emergence.

Rates also differed substantially between regions (Tindall and Kells, 2019). Sweet corn acres treated with atrazine in the North Central / Northeast region and in the Northwest region were, on average, treated with less than one pound of atrazine per acre annually. However, in the Southeast, sweet corn acres treated with atrazine were on average treated with over one pound of atrazine per acre annually. Across regions, 95% of atrazine (in pounds) was applied by ground equipment. Atrazine is used to target weeds like pigweeds, lambsquarters, ragweed, velvetleaf, sicklepod, and morningglory.

Previous Benefits

In 2019, BEAD found that atrazine was an important herbicide for use in sweet corn production, particularly for growers in the Southern tier of the United States (Tindall and Kells, 2019). BEAD found that atrazine was a preferred herbicide for sweet corn because it was economical; had a flexible use pattern, a long residual, and good crop safety; and was highly effective against a broad spectrum of weeds.

In 2019, BEAD found that the most likely alternative to atrazine prior to crop emergence in the North Central / Northeast region and in the Southeast is simazine, another triazine (Group 5) herbicide (Tindall and Kells, 2019). BEAD found that if growers lose access to atrazine but are still able to use simazine, growers in the North Central / Northeast and in the Southeast would face fairly small cost increases (equivalent to about a 5% decrease in net operating revenue) (Tindall and Kells, 2019). In the Southeast, both prior to crop emergence and after crop emergence, atrazine may be replaced with HPPD-inhibitors (Group 27) like mesotrione and VLCFA-inhibitors (WSSA Group 15) like s-metolachlor, though some growers may need a follow-up treatment with an herbicide like 2,4-D (WSSA Group 4) as the weed spectrum of these alternatives may be narrower than for atrazine. In the North Central / Northeast region prior to crop emergence, alternatives to atrazine include HPPD-inhibitor herbicides (WSSA Group 27) like mesotrione, though some growers may need a follow-up rescue treatment with an herbicide like 2,4-D (WSSA Group 4). In the North Central / Northeast region, BEAD found that in the absence of atrazine and simazine, grower herbicide control costs would likely increase by $13 per acre, equivalent to a 32% decrease in net operating revenue (Tindall and Kells, 2019). In the Southeast, BEAD found that in the absence of atrazine and simazine, grower herbicide costs could increase by $11-$52 per acre, equivalent to a 27%-100% decrease in net operating revenue. Additionally, growers may require upgrades in equipment to do directed postemergence sprays due to phytotoxicity concerns.

In the Northwest region after crop emergence, in the 2019 assessment, BEAD found alternatives included HPPD-inhibitor herbicides (WSSA Group 27) like topramezone or tembotrione, possibly tank-mixed with a Group 3 or Group 15 herbicide. In the Northwest, in the absence of atrazine, grower herbicide control costs would likely increase by $13 per acre, equivalent to a 32% decrease in net operating revenue.

BEAD found atrazine to be particularly important in the Southeast, where yield loss in the absence of atrazine and simazine was more likely due to the greater variety of weed pressure and the lack of available alternative active ingredients to target those pests and would result in additional revenue loss in addition to increased herbicide costs (Tindall and Kells, 2019).

New Information

Current Use and Usage

The most recent available usage information from 2015-2019 (Kynetec, 2020a) suggests that the use patterns for atrazine in sweet corn remains similar to the use patterns observed in BEAD's previous assessment. The most recent available usage data (Kynetec, 2020a) shows a decrease in the amount of atrazine applied to sweet corn relative to the usage from 2013-2017 observed in Tindall and Kells (2019). Based on 2015-2019 data, about 260,000 pounds of atrazine are applied annually to about 290,000 base acres of sweet corn (Kynetec, 2020a). However, the percentage of the crop treated with atrazine nationally from 2015-2019 remains similar to the percentage treated from 2013-2017 (Kynetec, 2020b). This is because nationally sweet corn acreage is decreasing – from 2015-2019, national sweet corn acreage planted declined by over 20% (USDA NASS, 2022).

Atrazine usage remains highest in the North Central / Northeast region, but the percentage of the sweet corn crop treated with atrazine remains highest in the Northwest and Southeast regions

(Table 2). Annual application rates in the Southern region are still higher than annual application rates in the North Central / Northeast region or the Northwest region. According to current usage information, 95% of atrazine applied to sweet corn is applied via ground applications; the remainder is applied aerially (Kynetec, 2020a).

Table 2: Atrazine Use in Sweet Corn by Region (2015-2019)

	National[1]	North Central / Northeast[2]	Northwest[3]	Southeast[4]
Total Pounds Applied	260,000	140,000	60,000	60,000
Total Acres Treated[5]	320,000	170,000	100,000	50,000
Average Single Application Rate (lbs/a.i./acre/year)	0.81	0.80	0.61	1.22
Base Acres Treated[5]	290,000	160,000	90,000	40,000
Average Annual Application Rate (lbs a.i./acre/year	0.88	0.88	0.67	1.27
Percent Crop Treated	66%	65%	78%	78%

Data from Kynetec (2020b), for years 2015-2019.
[1] Includes states in North Central / Northeast, Northwest, and Southeast, as well as California.
[2] Indiana, Illinois, Michigan, Minnesota, New Jersey, New York, Ohio, Pennsylvania, Wisconsin.
[3] Idaho, Oregon, Washington.
[4] Florida, Georgia.
[5] Acres may be treated more than once per year.

Current Benefits

According to state agricultural Extension agencies, atrazine continues to be recommended for weed control in sweet corn as an effective herbicide against important weeds in sweet corn, including herbicide-resistant ragweed, Palmer amaranth, and waterhemp (Loux et al. 2020, Mississippi State University Extension 2021). As atrazine continues to be effective, it is important in sweet corn as a tool for helping to delay the development of resistance to other herbicides.

Comments from Extension weed control specialists suggest that simazine is not a viable alternative to atrazine in sweet corn, as simazine does not have sufficient herbicidal activity on emerged weeds and provides poorer control of broadleaf weeds, the primary targets for atrazine (USDA OPMP, 2022).

As current usage indicates atrazine continues to be frequently used in sweet corn production, because current recommendations suggests that the benefits of atrazine are similar to the benefits found in BEAD's previous assessment, and because information from USDA OPMP (2022) suggests that simazine, the cheapest alternative to atrazine identified in 2019 (Tindall and Kells, 2019), is not a viable alternative to atrazine, BEAD concludes that the benefits of atrazine are likely larger in sweet corn than BEAD estimated in 2019, particularly for growers in Southern states and growers facing multiple-herbicide-resistant weeds.

Sorghum

Previous Assessment

Previous Use and Usage

BEAD previously assessed the use, usage, and benefits of atrazine to sorghum growers in 2019, using data from 2013-2017 (Tindall and Sells, 2019). BEAD found that 6.4 million pounds of atrazine were used on 4.8 million acres of sorghum annually; approximately 68% of all sorghum acres were treated with atrazine. On average, growers applied less than one pound of atrazine per application per acre annually to sorghum treated with atrazine. Approximately 69% of all atrazine applications (in acres-treated) to sorghum were made prior to crop emergence. Per-acre application rates prior to crop emergence in sorghum were on average similar to per-acre application rates after crop emergence in sorghum. 99% of atrazine applied to sorghum (in pounds) was applied by ground equipment. Almost half of sorghum acres treated with atrazine were treated twice with atrazine each year. Growers commonly targeted pigweeds and kochia with atrazine in sorghum both prior to crop emergence and after crop emergence.

Previous Benefits

In 2019, BEAD found that atrazine is an important herbicide for weed control in sorghum production (Tindall and Sells, 2019). BEAD found that atrazine was low cost; had a flexible use pattern, provided long residual weed control activity, and was highly effective against a broad spectrum of weeds both preemergence and postemergence.

BEAD's 2019 assessment found that prior to crop emergence, the most likely alternatives to atrazine in sorghum include the HPPD-inhibitors (Group 27) like mesotrione or PPO inhibitors (Group 14) like saflufenacil (Tindall and Sells, 2019). After crop emergence, propazine, a photosystem II inhibitor (WSSA Group 5, like atrazine), and the ALS-inhibitor herbicides (WSSA Group 2) like prosulfuron and halosulfuron are the most likely alternatives to replace atrazine. Propazine is not recommended for applications after sorghum emerges as it may harm the plant if used on certain soil types, and so may not always be a viable alternative to atrazine. However, none of these alternatives are as effective as atrazine against kochia and pigweeds; less weed control could lead to reductions in yield. To avoid yield loss, sorghum growers would need to rely on rescue treatments with dicamba (Group 4) or 2,4-D (Group 4), though these herbicides will increase control costs and can be phytotoxic to sorghum. Further, BEAD's 2019 assessment noted that some kochia and pigweed populations have developed resistance to ALS-inhibitor (Class 2) and HPPD-inhibitor (Group 27) herbicides, and so growers facing these weeds may have fewer or no effective alternatives to atrazine. Alternative herbicides to replace atrazine in sorghum may increase grower herbicide control costs by $5-$16 per acre, equivalent to a 21%-67% decrease in net operating revenue (Tindall and Sells, 2019). Additionally, growers may require upgrades in equipment to do directed postemergence sprays due to phytotoxicity concerns. If yield loss were to occur due to uncontrolled weed pressure, growers could suffer substantial losses – BEAD calculated that even a one percent yield loss could result in a ten percent decrease in grower net operating revenue.

New Information

Current Use and Usage

The most recent available usage information from 2015-2019 (Kynetec, 2020a) suggests that the use patterns for atrazine in field corn remains similar to the use patterns observed in BEAD's previous assessment. According to current usage information, about 6 million pounds of atrazine were applied annually to 4.4 million base acres of sorghum. About 70% of sorghum acres grown each year is treated with atrazine (Table 3). The most recent available usage data (Kynetec, 2020) shows a decrease in the amount of atrazine applied to sorghum relative to the usage observed in Tindall and Sells (2019); however, the percentage of the national sorghum crop treated with atrazine has remained relatively constant. This is because sorghum production has decreased nationally – average annual sorghum acreage harvested from 2015-2019 was 10% lower than the average annual sorghum acreage harvested from 2013-2017 (USDA NASS, 2022).

According to current usage information, 99% of atrazine applied to sorghum is applied via ground applications; the remainder is applied aerially (Kynetec, 2020a).

Table 3: Atrazine Use in Sorghum (2015-2019)

	National
Total Pounds Applied	5,990,000
Total Acres Treated[1]	6,700,000
Average Single Application Rate (lbs/a.i./acre/year)	0.89
Base Acres Treated[5]	4,430,000
Average Annual Application Rate (lbs a.i./acre/year	1.35
Percent Crop Treated	69%

Data from Kynetec (2020b), for years 2015-2019

[1] Acres may be treated more than once per year.

Current Benefits

Propazine was cancelled in 2021, and so this is no longer an available alternative to atrazine. According to state agricultural Extension agencies, atrazine remains an effective and recommended herbicide for weed control in sorghum (Lancaster et al. 2022, Johnson et al. 2020). As resistance to the likely alternatives to atrazine (including WSSA Group 2, Group 4, Group 14, and Group 27 herbicides) has been documented in some regions of the country (Heap 2021), growers facing resistant weed populations may find themselves with few or no suitable alternatives to atrazine. Based on the continued use of atrazine in sorghum in market research data, and the presence in some regions of resistance to likely alternatives to atrazine, BEAD concludes that the benefits of atrazine are likely larger in sorghum than BEAD estimated in 2019.

Sugarcane

Previous Assessment

Previous Use and Usage

BEAD assessed the use, usage, and benefits of atrazine in sugarcane as part of registration review in 2019 (McFarley and Lee, 2019). Sugarcane is grown in Florida, Louisiana, Hawaii, and Texas, but 95% of sugarcane acres grown in the United States were in Florida or Louisiana. Nearly all Florida sugarcane was treated with atrazine, and about one-third of Louisiana sugarcane was treated with atrazine. On average, two applications of atrazine were made annually to Florida sugarcane and one application is made annually to Louisiana sugarcane. Single application rates were also higher in Florida sugarcane production than in Louisiana sugarcane production – on average each application of atrazine made to Florida sugarcane was 3 lbs a.i./acre, while each application in Louisiana sugarcane was 2 lbs a.i./A. The average annual application rates are 6 lbs ai/A and 2 lbs ai/A per year in Florida and Louisiana, respectively. No aerial application of atrazine was reported on sugarcane in either state (McFarley and Lee, 2019).

Atrazine was used for preemergence and postemergence control of morning glory, winter broadleaf weeds, and some grasses (McFarley and Lee, 2019).

Previous Assessment

BEAD's 2019 assessment (McFarley and Lee, 2019) found that atrazine is an important herbicide in sugarcane weed control, particularly in Florida sugarcane production. BEAD found that unique advantages of atrazine compared to alternatives included longer residual control compared to alternatives, adequate crop safety, low cost, high efficacy on target weeds, and flexibility of use as atrazine can be applied both preemergence and postemergence.

BEAD found that in the absence of atrazine, growers in Florida would likely use metribuzin (Group 5) and ametryn (Group 5), or metribuzin (Group 5) and mesotrione (Group 27) (McFarley and Lee, 2019). The cost increases from using these alternative weed control scenarios range from $5/acre to $11/acre, which represents a decrease of approximately 2 to 4% in grower net operating revenue. For Louisiana, growers would likely replace atrazine with an application of metribuzin (Group 5) or mesotrione (Group 27), resulting in an increase in cost of $8 to $13 per acre, which represents approximately 11% to 17% of the baseline net operating revenue.

New Information

Current Use and Usage

Table 4 summarizes the most recent usage data, from 2012-2016, which is the most recent usage data available to the Agency. Kynetec no longer surveys sugarcane growers to collect data on pesticide usage.

Table 4: Use of Atrazine in Sugarcane (2012-2016)

	National[1]	Florida	Louisiana
Total Pounds Applied Annually	2,100,000	1,810,000	290,000
Total Acres Treated	800,000	650,000	160,000
Average Single Application Rate (lbs/a.i./acre/year)	2.62	2.80	1.86
Base Acres Treated[5]	530,000	400,000	130,000
Average Annual Application Rate (lbs a.i./acre/year	3.93	4.49	2.22
Percent Crop Treated	64%	98%	31%

Data from Kynetec (2020b), for years 2012-2016

[1] Sugarcane was only surveyed in Florida and in Louisiana.

Extension recommendations suggest that atrazine use has continued in sugarcane, with recommended single application rates of 2.4-4.4 lbs a.i./A in Florida (Odero and Dusky 2021) and 2.0-4.0 lbs a.i/A in Louisiana (Orgeron 2022). According to USDA OPMP (2022), the average annual application rate for atrazine in sugarcane is 6.0-8.0lbs a.i./A in Florida and 2.0-3.0lbs a.i./A in Louisiana. Further, information from USDA NASS suggests that a fairly consistent number of acres of sugarcane – about 900k annually - have been harvested from 2015-2019 (USDA NASS, 2022).

Based on available extension recommendations, BEAD expects that current use patterns for atrazine are likely similar to those assessed in 2019.

<u>Current Benefits</u>

Based on the continued recommendation of atrazine for weed control in sugarcane production (Odero and Dusky 2021, Orgeron 2022), BEAD expects that atrazine remains important for use in sugarcane production. Atrazine has accelerated dissipation in the organic soils of the Florida sugarcane growing region (Odero and Shaner 2014), and so higher application rates are needed in these soils to be effective against weeds because the period of residual activity is shorter in these soils than in the soils of Louisiana and Texas (Odero et al. 2019, Rott et al. 2018).

Atrazine continues to be a tool for herbicide resistance management in sugarcane. Unlike for the crops discussed above, herbicide resistance to weeds that atrazine is used to control is not widespread in sugarcane. However, state agricultural Extension agencies recommend using atrazine in herbicide mixes to delay the development of resistant weeds (Odero et al. 2018).

Other Use Sites

Atrazine is registered for use in other sites as well. Atrazine has agricultural registrations for use in guava, macadamia nuts, and wheat (fallow rotations only). Atrazine is also registered for non-agricultural use in rights-of-way, turfgrass, and nursery use. Since BEAD's assessment was conducted in 2019, registrants have recently cancelled several use sites (i.e., Roadsides; Conservation Reserve Program (CRP) land; conifers including Christmas tree plantings; timber and forestry; Miscanthus and other non-food perennial bioenergy crops) (US EPA, 2020). The Agency also banned the use of atrazine in Hawaii (US EPA, 2020), which accounts for a large proportion of both macadamia nuts and guava production in the United States.

In 2019, when assessing the benefits of atrazine in non-ag uses, BEAD found that atrazine is effective, inexpensive, and requires little additional management input because its effectiveness and optimum timing of its use is well understood after over 50 years of usage (Chism and Hanson, 2019). The most recent year with data available, suggested that thousands of pounds were applied to various use sites: nursery/ornamental (124,000 lbs), residential turfgrass (438,000 lbs [300,000 lbs homeowner applied; 138,000 lbs professionally applied]), and non-residential turfgrass (120,000 lbs) (Chism and Hanson, 2019). In 2019, BEAD found that atrazine is the most used herbicide with substantial residual activity in fallow systems (Tindall and Sells, 2019). On average, growers apply 989,500 pounds of atrazine to 1,140,800 acres annually, which accounts for about 3% of fallow acres that are treated with an herbicide (Tindall and Sells, 2019).

IMPACTS OF POTENTIAL ADDITIONAL MITIGATION

EPA is considering mitigation measures for use of atrazine in field corn, sweet corn, sorghum, and sugarcane production to reduce risks to aquatic organisms associated with off field movement of atrazine. These practices could include structural changes to the field, such as terraces or vegetated filter strips, or these could be changes to grower agronomic practices, such as using lower rates of atrazine or growing cover crops. These practices could be required individually or EPA could consider a pick-list system, requiring growers to select some number of practices from a set of options. The full list of practices considered is below:

- *Agronomic mitigations*
    - *No preemergence applications*
    - *Rate reductions (annual and preemergence)*
    - *No aerial applications*
    - *No applications to saturated soils*
    - *No applications before rainfall*
    - *Soil incorporation of atrazine to a depth of 1 inch*
    - *No tillage or reduced tillage*
    - *Cover crops*
    - *Irrigation water management*
- *Structural mitigations*

- *>30 ft or >100 ft vegetative filter strips*
- *Field border*
- *Grassed waterway*
- *Contour buffer strips*
- *Terrace farming*
- *Contour farming*
- *Strip cropping*
- *Vegetated ditch banks (sugarcane only)*

BEAD assesses the cost or degree of difficulty of complying with each mitigation individually below and identifies crop and regional differences in the viability of adoption of each practice.

Agronomic Mitigations

The following agronomic practices may be feasible for some growers to adopt on an annual basis. Growers may want to apply atrazine in one growing season but not another (*e.g.*, in a corn-soybean rotation), and would be able to utilize these practices only when they want to apply atrazine.

No Preemergence Applications

Applications of atrazine prior to crop emergence are more susceptible to runoff because there is no crop vegetation in the field to slow runoff or absorb excess water. Therefore, prohibiting preemergence applications is expected to decrease atrazine runoff after a rainfall event. As described in Table 5, the timing that growers choose to apply atrazine varies by crop and region (Table 5). Most atrazine applications to sorghum are made prior to crop emergence; most atrazine applications are also made prior to crop emergence in sweet corn in the North Central / Northeast region. In all regions, the majority of atrazine applications made to field corn are also made prior to crop emergence.

Table 5 Atrazine Rates Prior to Crop Emergence for Field Corn, Sweet Corn, Sorghum, and Sugarcane, by Region (2015-2019).

Crop	Percent of Total Acres Treated Prior to Crop Emergence	Mean Per-Acre Single-Application Rate Prior to Crop Emergence
Field Corn[1]	59%	0.98
Corn Belt	62%	1.00
Plains States	63%	0.95
Southern Seaboard	58%	1.21
Sweet Corn[1]	49%	0.93
North Central / Northeast	62%	0.89
Northwest	29%	0.66
Southeast	45%	1.51
Sorghum[1]	80%	0.90
Sugarcane[2]	10%	2.62
Florida	10%	2.77
Louisiana	5%	1.95

Regions defined in Tables 1, 2, and 4. Maximum single application rates are 2.0lbs/A in field corn, sweet corn, and sorghum, and 4.0lbs/A in sugarcane.
1 Kynetec, 2020a, for years 2015-2019
2 Kynetec, 2020a, for years 2012-2016

Growers could use atrazine after crop emergence instead of before crop emergence but the ability to shift the timing of application would vary depending on the crop and the weeds being targeted. Information provided by USDA OPMP suggest that both preemergence and split preemergence/postemergence applications of atrazine are highly important for weed control programs for both corn and sorghum growers in the Corn Belt and Southern Plains, primarily for control of broadleaf weeds prior to planting (USDA OPMP, 2022). Growers often time herbicide applications based on when targeted weeds emerge, and so applications before or after crop emergence may not be direct substitutes for each other in all crops and regions.

For example, pigweeds are weeds frequently targeted by atrazine applications in several field corn-growing regions. Palmer amaranth (*Amaranthus palmeri*) germination depends on soil temperature, tillage practices, and other factors, and can occur as early as March in California (Keeley et al. 1987), in mid-May to June in Arkansas (Bell et al. 2015), and in June and early July in Nebraska (Chahal et al. 2021). Atrazine can control pigweeds either before they emerge or after they emerge but are still small. Applications of atrazine targeted to control Palmer amaranth could occur both before or after crop emergence. Growers who currently use atrazine before crop emergence for residual control of Palmer amaranth may not be able to use atrazine after crop emergence for this purpose as the weeds are already emerged and may be too large for adequate postemergence control with atrazine. This situation applies not only to pigweeds, like Palmer amaranth, but any weed species targeted with atrazine by growers.

Field corn, sweet corn, and sorghum growers who otherwise would apply atrazine before crop emergence but delay the application to after crop emergence instead could incur additional costs from the addition of surfactants or other herbicides to control emerged weeds or face reduced weed control. Growers who would normally apply atrazine both before and after crop emergence would have to use an alternative herbicide to replace the preemergence application or rely on additional herbicides during the postemergence application timing; these growers may face impacts equivalent to replacing atrazine prior to crop emergence described in the Benefits sections above.

Because sugarcane is a perennial crop, atrazine use is more nuanced and variable in sugarcane compared to field crops. In Florida, preemergence applications are mainly used in the year that the sugarcane crop is planted (plant cane) while in subsequent years (ratoon cane), preemergence applications are rare. Preemergence applications are also used in Louisiana for plant cane and information provided by USDA OPMP indicate that about 20% of acres use atrazine as part of the spring preemergence burndown in ratoon cane (USDA OPMP, 2022). Sugarcane growers may be able to replace atrazine as part of burndown applications in ratoon cane, but may struggle to replace atrazine for weed control in plant cane, instead relying on alternatives that will increase costs by up to $11/A in Florida and up to $13/A in Louisiana.

Rate Reductions

Limiting annual maximum annual rates of atrazine would reduce the amount of atrazine entering the environment by limiting the total potential amount of atrazine that could be applied. BEAD considered two ways application rates could be reduced: lower the maximum allowable application rates prior to crop emergence and/or lower the maximum annual rates. The latter could be achieved by growers reducing the rate of each separate application or by reducing the total number applications. A slight reduction in the allowed application rate may result in a slight reduction in weed control which the grower may still consider acceptable, while a large reduction in application rate is likely to result in poor weed control leading to reduced yield or increased control costs. Growers could compensate for the reduced rate by mixing other herbicides with atrazine or potentially by replacing atrazine entirely.

<u>Impacts of rate reductions on herbicide resistance management</u>

If the Agency limits grower atrazine rates, some growers may be incentivized to use atrazine at rates lower than they were using previously. Even small reductions in application rates, will likely have substantial implications for herbicide resistance management. To avoid resistance developing to an herbicide, the herbicide must be applied at a rate that is sufficient to fully control the weed being targeted otherwise tolerant individuals will survive and reproduce. If atrazine rates are reduced below the effective rate for the weed being targeted, then that weed species is more likely to develop resistance to atrazine.

Furthermore, using multiple effective modes of action for a target weeds species is highly important to herbicide resistance management (US EPA, 2017). Atrazine is frequently applied as part of a premix or tank mix with many other classes of herbicides including the 4-hydroxyphenylpyruvate dioxygenase (HPPD) inhibitor herbicides (WSSA Group 27) and very long chain fatty acid inhibitor herbicides (WSSA Group 15). Tank mixes of two or more herbicides can prevent or delay the development of herbicide resistance if herbicides with different sites of action are tank mixed together to target the same weeds (Sprague, 2018, Culpepper and York, 2018). If the rate of atrazine in a premix or tank mix is below the effective rate necessary to control the weed species, then there is increased selection pressure on the premix or tank mix partner herbicides.

<u>Reduced maximum annual application rates</u>

Currently, the maximum annual rate is 2.5 lbs of atrazine per acre for field corn, sweet corn, and sorghum, while the annual maximum rate for sugarcane is 10 lbs of atrazine per acre. For instance, lowering rates to 2.0 lbs a.i./acre and 8.0 lbs a.i./acre, respectively, represents a 20% reduction in annual rates. EPA is considering reducing maximum annual rates for atrazine. Lowering maximum rates would be expected to reduce the total amount of atrazine entering the environment.

Per-acre impacts

Growers currently using atrazine at rates over the new maximum rate would either need to reduce their rate to the maximum or else seek alternatives to atrazine.

Some growers may be able to reduce their effective application rates by use of banded applications, in which atrazine is applied in a limited band over the crop rows. Banded applications would allow growers to maintain use of higher effective atrazine rates within the band, while still decreasing the total amount of atrazine applied to the acre. The challenge with banded applications is weed control in the areas between the bands. Often with banded applications, chemical weed control between bands is replaced with mechanical cultivation. Mechanical cultivation is not compatible with production systems like no-till and requires specialized cultivation equipment which growers may not have readily available. Cultivation is also slower than herbicide application and may result in negative environmental effects.

Growers who use multiple applications of atrazine may be able to reduce their annual atrazine rates by replacing one or more of their applications with alternative herbicides. Since these growers would be able to continue using atrazine at their usual rate for other applications, BEAD does not expect these growers would see reduced efficacy for their remaining atrazine applications. Other growers may use lower rates of atrazine while tank-mixing higher rates of other herbicides, such as HPPD-inhibitors, to improve control of target weed species. These growers may suffer worse weed control than using atrazine at their usual rate and/or may face increased control costs. Further, using atrazine below the effective rate may contribute to the development of weed resistance to atrazine.

The feasibility of a grower complying with a reduced maximum annual rate depends on the new maximum rate. The lower the maximum rate, the more growers would be affected by this mitigation. This is illustrated in Table 6 by field corn: while 90% of acres treated with atrazine are treated with 2.0lbs of atrazine or less per acre each year, only about 50% of acres treated with atrazine are treated with 1.0lbs of atrazine or less per acre each year and only about 20% of acres treated with atrazine are treated with 0.625lbs of atrazine or less per acre each year. Further, the lower the maximum rate, the harder it would be for affected growers to comply with the mitigation. Growers who are already tank-mixing atrazine with other herbicides or are already using banded applications may not be able to reduce their rate any further. Substantial reductions are more likely to mean that banded applications and tank-mixing lower rates of atrazine are less feasible, and growers will be forced to switch completely to alternative herbicides, facing impacts including reduced weed control or substantially increased herbicide costs as described above.

Regional impacts

Information on atrazine use rates prior to crop emergence, by region and by crop, are provided in Table 6.

Restrictions on annual application rates would be most impactful for Southern growers of field corn and sweet corn. Atrazine is used at substantially higher rates in the South than in other regions of the country (Table 6), and so a reduction in atrazine rates would affect a greater proportion of growers and have a higher per-acre cost. For instance, a maximum annual rate of 1.5lbs ai/A in field corn would be above the average atrazine application rate in the Corn Belt (1.24 lbs ai/A) but would be below the average application rate in field corn in the Southern Seaboard region (1.65 lbs ai/A). Over 70% of field corn acres treated with atrazine in the Corn Belt are treated below 1.5lbs ai/A and would not be restricted by a 1.5lbs ai/A restriction, while only 40% of field corn acres in the Southern Seaboard are treated below 1.5lbs ai/A (Table 6). This illustrates that Southern growers will find any given cutoff more restrictive than growers in other regions. Average rates are also higher for Southern sweet corn growers compared to sweet corn growers in other regions, and so any given cutoff will also be more restrictive for Southern sweet corn growers relative to growers in other regions. BEAD expects the same pattern will likely hold in sorghum production as well.

As discussed in the Benefits sections for field corn and sweet corn, the benefits of atrazine are particularly high for growers in the Southern U.S. If annual atrazine rates are reduced below effective rates, Southern field corn growers may be unable to control certain weed species and may suffer substantial losses in yield and net operating revenue. The application rate of atrazine that is needed to be effective can vary depending on weeds present, region, soil type, and other factors, and so rate reductions will not have the same impact on every grower. Southern sweet corn growers would also be more likely to suffer yield loss than sweet corn growers in other regions of the country due to high weed pressure and lack of suitable alternatives.

Distributions of annual rates are not available for sweet corn, sorghum, or sugarcane. Heuristically, rate restrictions near the mean per-acre annual rate in any crop-region (Table 6, column 2) are likely to restrict many or most growers of that crop in that region.

Table 6: Annual Atrazine Rates for Field Corn, Sweet Corn, Sorghum, and Sugarcane.

Crop	Mean Per-Acre Annual Application Rate (lbs/A/y)[1]	Average Number of Applications per Acre[1]	Percent of Annual Per-Acre Rates Above Rate[6]			
			2.0lbs/A[2,3]	1.5lbs/A[2,3]	1.0lbs/A[2,3]	0.625lbs/A[2,3]
Field Corn[4]	1.18	1.3	10%	28%	49%	79%
Corn Belt	1.24	1.3	11%	30%	54%	84%
Plains States	1.11	1.3	9%	22%	45%	76%
Southern Seaboard	1.65	1.3	20%	60%	80%	95%
Sweet Corn[4]	0.88	1.1	Data unavailable			
North Central / Northeast	0.88	1.1				
Northwest	0.67	1.1				
Southeast	1.27	1.0				
Sorghum[4]	1.35	1.5				
Sugarcane[5]	3.9	1.5				
Florida	4.5[1] / 6-8[7]	1.6				
Louisiana	2.2[1] / 2-3[7]	1.2				

1 Kynetec, 2020b. Years 2015-2019 for field corn, sweet corn, sorghum. Years 2012-2016 for sugarcane.
2 Kynetec, 2020a. Years 2015-2019.
3 Proportion of acres treated at higher rates may be underestimated because a grower may treat only part of a field with atrazine a second time. Data would show the annual application rate averaged across the entire field rather than distinct rates for the separate portions of the field.
4 Current annual maximum rate in field corn, sweet corn, and sorghum is 2.5lbs a.i./A.
5 Current annual maximum rate in sugarcane is 10lbs a.i./A.
6 2.0lbs of atrazine is equivalent to a 20% reduction in atrazine rate for field corn.1.5lbs is equivalent to a 40% reduction; 1.0lb is equivalent to a 60% reduction, and 0.625lbs is equivalent to a 75% reduction
7 USDA OPMP, 2022

BEAD also expects that a reduction in application rates for sugarcane would be more impactful for Florida sugarcane growers, who use substantially higher rates, on average, than Louisiana sugarcane growers (Table 6) due the accelerated dissipation of atrazine on the organic soils where sugarcane is grown in Florida. Growers who must reduce the rates at which they normally apply atrazine would likely face increased herbicide control costs and additional costs for scouting or require purchasing equipment for directed sprays.

Reduced maximum rates are more likely to be especially burdensome for growers who apply atrazine multiple times per year. Multiple applications per year are common in sorghum and Florida sugarcane, but less common in sweet corn (Table 6).

Managerial effort impacts

Many growers currently apply atrazine using premixed herbicide products. However, in order for growers to reduce their atrazine rates, many growers may no longer be able to utilize currently formulated premix products or will have to use tank-mixes to increase the rate of herbicide partners. While growers will be able to re-create their desired premixes at their desired rates using tank-mixes, this will require increased managerial effort: purchasing the correct products, choosing rates, and additional mixing and loading steps.

<u>Reduced maximum preemergence application rates</u>

Applications of atrazine prior to crop emergence are more susceptible to runoff because there is no crop vegetation in the field to slow runoff or absorb excess water. EPA is considering reducing maximum pre-emergence application rates for atrazine.

Per-acre impacts

Growers who use atrazine over the new maximum preemergence rates will need to either reduce the rates they use, change when they apply atrazine, or seek alternative herbicides to replace atrazine.

As described in the previous section on annual rate reductions, some growers may be able to reduce their rates by using banded applications, tank-mixing lower rates of atrazine with higher rates of other herbicides, or by replacing atrazine completely with other herbicides. These growers will face substantial impacts, including increased herbicide costs and reduced control, as described in Benefits above. However, growers using atrazine prior to crop emergence have another option, which is to switch their atrazine application from prior to crop emergence to after crop emergence. Switching atrazine applications to after crop emergence may result in worse control of early season weeds or increased herbicide control costs as growers replace atrazine with more expensive alternatives prior to crop emergence or with directed postemergence sprays to control emerged weeds.

Also as described in the previous section on annual rate reductions, the impacts to a grower of a reduced maximum pre-emergence rate depends on the new maximum rate. At lower maximum pre-emergence rates, more growers will find their current rates above the new maximum. Further, at lower maximum pre-emergence rates, fewer growers will be able to feasibly reduce rates via banded applications or by tank-mixing with other herbicides and will need to either move their atrazine applications to after crop emergence or entirely replace atrazine in their herbicide control program. These growers will face substantial impacts, including increased herbicide costs and reduced control, as described in Benefits above.

Regional impacts

Information on atrazine use rates prior to crop emergence, by region and by crop, are provided in Table 5.

Reduced maximum preemergence (to the crop) rates would be more impactful for growers in crops where atrazine is frequently used prior to crop emergence. Most atrazine applications to sorghum are made prior to crop emergence; most atrazine applications are also made prior to crop emergence in sweet corn in the North Central / Northeast region. In all regions, the majority of atrazine applications made to field corn are also made prior to crop emergence.

This mitigation would also be more impactful for regions where growers who use high atrazine rates prior to crop emergence, as more growers would be restricted by any given reduced maximum pre-emergence rate. Atrazine is used at substantially higher rates prior to crop emergence in the South than in other regions of the country, and so a uniform restriction on atrazine rates would be most impactful for these growers.

This potential mitigation would be less impactful to growers of crops which are rarely treated prior to crop emergence. The vast majority of atrazine applications made to sugarcane, in all regions, are made after crop emergence (Table 5). Atrazine is also usually applied after crop emergence in sweet corn production in the Northwest region (Table 5).

No Aerial Applications

In all four of the assessed major use sites for atrazine, the vast majority of atrazine (in pounds) is applied via ground application. According to the most recent available market research data (Kynetec, 2020a), 99% of atrazine applied to field corn, 95% of atrazine applied to sweet corn, and 99% of atrazine applied to sorghum are applied via ground equipment; the remainder is applied aerially. While recent market research data are not available for sugarcane, in the most recent available market research data from 2012-2016 (McFarley and Lee, 2019), no aerial application of atrazine was reported in sugarcane.

Atrazine can be applied aerially when the ground is too wet for ground equipment to enter the field. While this does not occur frequently, aerial applications are important for growers in this situation. If aerial applications are not allowed, growers may have to delay applications until a time they are able to do an application with ground equipment, potentially resulting in reduced control of weeds. Alternatively, growers could apply an alternative herbicide by air which may impact growers by requiring the use of a more expensive or less efficacious herbicide to control the target weed or weeds. The burden of this mitigation will be more substantial if aerial applications of atrazine alternatives are also restricted. Outside of this circumstance, BEAD does not expect this mitigation to be impactful to growers of field corn, sweet corn, sorghum, or sugarcane, because atrazine is rarely applied aerially.

No Applications to Saturated Soils

As a prohibition on aerial applications is also being considered, atrazine could only be applied with ground equipment. Generally, growers already aim to avoid driving equipment in fields when the soils are saturated so impacts are expected to be minimal. While ground application to saturated soils is unlikely, the application window for some weed species targeted by atrazine applications is narrow and growers may need to apply herbicides when soil conditions are saturated. Therefore, the soil saturation restriction could reduce the ability of growers to apply atrazine especially when coupled with a prohibition on aerial applications, potentially resulting in reduced control of problematic weeds. The impact to users would also vary by soil textural class, as soils with greater clay content will retain water longer than sandier soils, possibly affecting the potential application window for atrazine.

No Applications Before Rainfall

Implications for Available Application Time

Limiting atrazine applications when rain is forecasted may reduce runoff from fields by avoiding exposing atrazine to rainfall that could cause a runoff event and carry atrazine off-field. Restricting applications when rain is expected may limit the available hours applicators are able to apply atrazine and could delay time-sensitive herbicide applications. The impact from this mitigation would vary based on the prevailing frequency of rainfall in the area of the country where atrazine is being applied. The impact of this mitigation will also differ depending on how many days before a rain event application of atrazine is restricted. If rainfall is frequent enough or if the timing restriction is substantial enough, it could prevent growers from applying atrazine in a timely manner for effective weed control, possibly resulting in poor weed control or necessitating the use of alternative herbicides that do not have the rainfall restriction.

This potential mitigation, in combination with the potential restriction on aerial applications and the potential restriction on applications to saturated soil, would mean that growers would be unable to apply atrazine in the period from the start of the forecasted rain restriction until after the soil is no longer saturated and also until ground equipment is able to enter the field. In some cases, a short delay may not have a large impact if growers are still able to apply atrazine to targeted weeds at the appropriate stage. However, timely applications of atrazine are necessary to achieve control of targeted weeds, like Palmer amaranth, and if these weeds are already emerged there may be substantial impacts to waiting for an application window. Palmer amaranth growth rates can be 2-3 inches per day (Legleiter and Johnson, 2013) and emerged plants need to be treated by atrazine when they are less than 6 inches tall, and so the window for atrazine applications is very narrow, likely only a couple of days.

If growers need control in this period, they may either seek alternatives to atrazine, or may rely on post-emergence rescue treatments. Alternative control methods may increase grower control costs, and in some regions may fail to provide adequate control of important pests, potentially resulting in yield or quality losses. Larger acreage productions may be more heavily impacted by this potential mitigation, as growers may find it difficult to treat larger acreages in the remaining viable application windows.

Implications for Activation of Atrazine

Previous memos indicated that the residual control of weeds prior to their emergence is a primary benefit of atrazine. In order for weeds to be controlled prior to emergence, rainfall or irrigation is required to activate the herbicide (Everman, 2008). Water from rainfall or irrigation stimulates germination of weeds and helps with the uptake of the herbicide into the germinating weeds. An activating rain is needed within 10 to 14 days after application for best weed control. However, too much water can be detrimental too because excessive rain or irrigation can move the herbicide below the depth of weed seed in the soil such that germinating seeds do not come in contact with the herbicide (Everman, 2008). Therefore, a restriction that limits application shortly before any rainfall could prevent activation and disrupt farmers' ability to control weeds in a timely manner. However, because too much rain also can negatively impact the efficacy of an application, growers would not apply before a rainfall event that would be likely to produce runoff.

Therefore, BEAD concludes that a restriction encompassing any amount of rain would be burdensome and prevent activation that is needed for atrazine to be effective. However, if restrictions are defined in a manner that account for rains that are likely to produce a runoff event, the impacts would be minimal as BEAD assumes this would be in line with normal best management practices.

Soil Incorporation

Applications of atrazine that are made before crop planting can be incorporated into the soil by mechanical incorporation after application. The incorporation of atrazine into the soil profile reduces the likelihood of atrazine leaving the field during a rainfall event. The ability of a grower to incorporate atrazine into the soil depends on many factors including their tillage system, the availability of equipment to enable incorporation, and the tank mix partners with which atrazine is applied. A preplant mix often includes a residual herbicide like atrazine to control unemerged weeds and a contact herbicide to control already emerged weeds. Many contact herbicides need to be applied to foliage and are not effective in the soil, and so they could not be tank mixed with an atrazine application that the grower intended to incorporate. Soil incorporation of atrazine can only be accomplished for preplant applications. Therefore, soil incorporation of atrazine is necessarily incompatible with restricting preemergence applications. Furthermore, requiring soil incorporation would also be requiring a form of tillage, meaning that this mitigation could not be used with no-tillage and reduced tillage production systems that are or may potentially be used by corn and sorghum producers. Soil incorporation is likely not feasible in a perennial crop like sugarcane, except possibly in the year that the sugarcane is planted (plant cane) and is likely not feasible for growers of a crop like sweet corn who predominantly use postemergence applications of atrazine (USDA OPMP, 2022).

Using a No-Till or Reduced-Tillage Production System

While tillage has many uses in crop production, including weed control and seedbed preparation, there has been increasing adoption of no-till and reduced tillage production systems (Horowitz et al., 2010; Uri, 1998; Claassen et al., 2018). About 65% of corn acres (USDA NASS, 2022) and 66% of sorghum acres (USDA NASS 2020) are currently planted as no-till or minimum tillage. No-till and reduced tillage production systems minimize the amount of soil disturbance through tillage. These systems reduce herbicide, sediment, and nutrient losses through runoff water, prevent soil erosion, increase soil organic matter which can help to improve soil structure and subsequently water infiltration into the soil which helps keep atrazine in the field. Converting from a conventionally tilled system to a no-till or reduced tillage system reduces grower costs by reducing the number of equipment passes across the field for tillage operations. However, growers switching to a no-till and reduced tillage system would likely need to invest in new planting equipment designed to properly plant seed under high crop residue conditions and may spend more on herbicides, as tillage would no longer be a tool for weed control. Sugarcane growers are likely able to adopt a no-till system as cultivation is an important weed control tactic in sugarcane, but reduced tillage may be possible at some parts of the multi-year sugarcane cropping cycle (Gravois et al. 2011). Additionally, sweet corn cannot be successfully produced in a no-till or reduced tillage systems because sweet corn seed has low vigor and does not produce adequate stands under the high-plant residue conditions associated with reduced till and no-till systems (USDA OPMP, 2022).

<u>Leave Sugarcane Residues on Field After Harvest (Sugarcane Only)</u>

Sugarcane is a vigorous perennial crop that produces significant amounts of biomass. As the sugarcane stalk or cane is the only part that is harvested, growers must manage plant residues generated by the other parts of the sugarcane plant. These residues can be managed by preharvest burning of the sugarcane field or harvesting the sugarcane green and either burning the residue or leaving the residue in the field. Leaving un-burned sugarcane crop residue on the field after the crop is harvested protects the soil and increases water infiltration into the soil profile after a rainfall event. However, leaving crop residues on sugarcane fields may negatively affect the subsequent sugarcane crop. Leaving the crop residue can result in sufficient amounts of water remaining in the field to hinder fieldwork the following season. Plant residues also shield also slow the rate that soils warm in the spring which affect drying of the sugarcane field and limit early-season sugarcane growth potentially resulting in significant yield loss. Information provided by USDA OPMP indicate that ~80% of sugarcane fields in Florida are burned prior to harvest but the number of sugarcane fields in the state that are green harvested are increasing. In contrast only ~20% of growers in Louisiana burn fields prior to harvest with the remaining being green harvested. However, 3-7 days after harvest, the residues left in the field are burned. The fields are burned to improve soil warming and drying the following season. State Extension specialists in Louisiana indicate that postharvest burning only removes 50-60% of the sugarcane residue (USDA OPMP, 2022). BEAD concludes that leaving sugarcane plant residues on the field after harvest is not feasible.

Cover Crops

Using cover crops before the crop where atrazine will be used is being considered as a mitigation to address runoff concerns for atrazine. Cover crops are a separate crop planted after the main crop is harvested in the fall in order to keep vegetated cover and/or plant residues on the soil until the next cash crop is planted. The plant material that cover crops provide slow runoff and help to increase water infiltration into the soil and thereby reduce runoff. However, there are costs associated with cover crop establishment including seed costs, planting costs, termination costs and additional managerial effort.

For sugarcane in Florida, cover cropping is not feasible because of the year-round sugarcane growing season and continuous crop rotation with no fallow period in which to grow a cover crop. In Louisiana and Texas, growers can use a cover crop during the fallow season after the end of the multi-year sugarcane cropping cycle (ratoon cane) and prior to planting the subsequent sugarcane crop (plant cane). Cover crops are also not suitable for use with sweet corn as the plant residues left by the cover crop hinder stand establishment for the low-vigor sweet corn seed. Information gathered by USDA OPMP from multiple state agricultural Extension specialists suggest that cover crops are feasible to be incorporated into corn and sorghum production systems where adequate rainfall or irrigation is available (USDA OPMP, 2022). However, USDA indicated that in dryland production areas, such as the Plains states, with limited rainfall, cover crops are not feasible because they deplete soil moisture necessary for establishment and growth of the corn or sorghum crop as well as subsequent crops in the rotation (USDA OPMP, 2022).

Irrigation Water Management

Irrigation water management refers to the process of determining and controlling the volume, frequency, and application rate of irrigation water to reduce runoff of water and pesticides from fields resulting from irrigation. While irrigation water management may result in more efficient irrigation and water use, it requires managerial expertise by operators and may require the purchase of specialized equipment such as soil moisture sensors and equipment to monitor plant water status in order to more effectively control the volume, frequency, and rate of water application to a field.

Irrigation water management is likely feasible for growers on irrigated land of all four crops where atrazine is used. However, irrigation water management can only be conducted on irrigated land. This mitigation cannot be imposed on dryland production.

Irrigation is uncommon in field corn production in the Corn Belt, but is more frequently utilized in field corn production in the Great Plains and Southern Seaboard regions – for instance, according to the 2017 Census of Agriculture less than 10% of field corn acres in Iowa, Illinois, Minnesota, Indiana, and Ohio are irrigated, while over 50% of Nebraska and Colorado field corn acres, and over 50% of Georgia field corn acres, are irrigated (USDA NASS, 2022). Irrigation is uncommon sorghum production – – according to the 2017 Census of Agriculture, in the two largest sorghum producing states, Kansas and Texas, only 4% of Kansas sorghum and 10% of Texas sorghum are irrigated (USDA NASS, 2022). Sweet corn is frequently irrigated in all regions of the country, especially the Southeast and the Northwest – – according to the 2017 Census of Agriculture, 50% of Washington and Oregon sweet corn acres, and over 50% of Florida and Georgia sweet corn acres, are irrigated (USDA NASS, 2022). In sugarcane, – according to the 2017 Census of Agriculture, over 99% of Florida sugarcane grown for sugar is irrigated, while less than 1% of Louisiana sugarcane grown for sugar is irrigated (USDA NASS, 2022).

Structural Mitigations

The following agronomic practices cannot be adopted without first undertaking substantial investment. These practices could require a substantial period of time to implement and could be very difficult to remove once implemented. BEAD expects that it is unlikely that growers would adopt these practices only to be able to use atrazine. Growers using land they do not own may find it especially difficult to adopt these mitigations if the landowner does not want to make the investment to make permanent structural measures that address runoff. However, some growers may already be utilizing these practices due to the other agronomic benefits they provide.

Vegetative Filter Strips

Vegetative filter strips (VFS) are strips of land in permanent vegetation designed to protect sensitive downslope areas from runoff from agricultural fields. VFS slow water movement and increase water infiltration, reduce runoff, and remove sediment and pesticides from runoff. However, VFS can be highly impactful for growers, especially those with small fields because they may remove land from production. VFS may also be costly to maintain.

To characterize the effect that vegetated filter strips may have on growers, BEAD uses field size data from the USDA Farm Service Agency (FSA) to calculate the percent of field corn, sweet corn, sorghum, and sugarcane fields lost to 30-foot and 100-foot strips by field size at various field sizes. BEAD assumes a rectangular field with width equal to twice its length, with the vegetated filter strips on the long side of the field. Vegetated filter strips are more impactful for smaller fields, as they account for a larger proportion of the field. As an example, for sweet corn fields in the smallest 10th percentile of field size, a 30-foot vegetated filter strip would result in the loss of 7% of acreage. For fields at the 50th percentile of field size, a 30-foot vegetated filter strip would result in the loss of 3% of acreage, while at the 90th percentile, it would result in the loss of 2% of acreage. Losses are larger for 100-foot vegetated filter strips (Table 7). For a regularly shaped field, the area affected is linear in the size of the VFS. Less area is affected if the VFS must be installed on a shorter side.

Table 7: Distribution of Field Corn, Sweet Corn, Sorghum, and Sugarcane Field Sizes and Impacts from One Sided Downslope Vegetated Filter Strips on Rectangular Shaped Fields Where the Vegetated Filter Strip is on the Long Side

		10th Percentile			50th Percentile			90th Percentile		
Crop	**VFS (ft)**	**Field Size Acres**	**Percent Impacted by VFS**	**Percent of Fields Smaller than Percentile**	**Field Size Acres**	**Percent Impacted by VFS**	**Percent of Fields Smaller than Percentile**	**Field Size Acres**	**Percent Impacted by VFS**	**Percent of Fields Smaller than Percentile**
Corn	**30**	13	6	50	61	3	87	153	2	99
	100	13	19	50	61	9	87	153	5	99
Sweet Corn	**30**	9	7	64	56	3	91	141	2	99
	100	9	22	64	56	9	91	141	6	99
Sorghum	**30**	20	5	48	79	2	86	235	1	99
	100	20	15	48	79	8	86	235	4	99
Sugarcane	**30**	4	10	40	19	5	86	48	3	99
	100	4	34	40	19	16	86	48	10	99

Data from USDA FSA, 2010-2014. Percentiles indicate the proportion of total acreage in fields of a given size. For example, ten percent of the field corn acreage in the FSA sample is concentrated in fields of 13 acres or less.

Aside from taking land out of production, growers would incur costs to establish and maintain vegetated filter strips in fields. USDA OPMP previously provided cost estimates for a vegetated filter strip. Based on the USDA NRCS payment schedule for California USDA estimated the cost of establishing a vegetated filter strip to be $165 – $927 per acre of strip (USDA OPMP, 2018). Yearly maintenance costs were estimated to be $40 to $240 per acre of strip (for mowing or weed control applications). Costs, including labor costs, would differ across states and regions and also vary according to the size and shape of the field. Use of vegetative filter strips is likely feasible in all crops, assuming the cost and loss of production area does not outweigh the benefits of using atrazine.

Field Border

A field border is a strip of permanent vegetation on one or more sides of a field. The border can be converted cropland, but may also be created by removing large trees from a field border and leaving a transition zone of herbaceous plants. Field borders reduce sediment and pesticides leaving the field by controlling and filtering runoff. The establishment of field borders may take land out of production, similar to a VFS, and there are costs associated with establishing and maintaining field borders, including costs associated with tree removal, herbaceous cover establishment and weed control.

Similar to VFS, fields borders are likely feasible in all crops, assuming the cost and loss of production area does not outweigh the benefits of using atrazine.

Grassed Waterways

A grassed waterway is a shaped or graded channel that is established within a field to convey water in a non-erosive way off the field. Grassed waterways are usually planted with perennial grass species but can contain other suitable plant species as well. Similar to VFS, land is removed from production and there are costs associated with establishing and maintaining them, including costs associated with herbaceous cover establishment and weed control. Because these grass waterways may involve land grading within the field, this practice can involve substantial planning and may affect cropping on the land in future years.

Similar to VFS, grassed waterways are likely feasible in all crops, assuming the cost and loss of production area does not outweigh the benefits of using atrazine. However, in fields that are flat and have limited slope, there may not be specific waterways to leave vegetated, meaning that grassed waterways may not be suitable for all fields.

Contour Buffer Strips and Terracing

Contour buffers are permanent established strips of perennial grasses alternating between wider cultivated strips that follow the contours of sloped land. Terraces are similar to contour buffers but involve the creation of semi-permanent earthen embankments or ridges built across the slope of a field and, depending on the type, are established in permanent cover. Contour buffers and terraces slow runoff water allowing for increased infiltration and filtering of sediment and pesticides within the runoff water. Contour buffers are generally easier to establish and cost less to implement than terraces, which require the building of embankments. Both practices take land out of crop production, similar to vegetative filter strips, with the impacts varying by field shape and size. Both require significant planning and investment to implement, and there are maintenance costs associated with both practices. Because these practices involve establishing embankments and/or semi-permanent vegetated strips within the field, this practice may affect cropping on the land in future years. Contour farming and terracing practices are designed to reduce runoff on sloped fields. Generally, terraces would likely be utilized on significantly steep slopes, while contour buffers would generally be utilized on more moderately sloped fields and would be unlikely to be used together. These practices are not applicable to flat land as there is no slope to follow and would likely not have the same effect in reducing runoff on flat fields as on sloped fields. These practices are likely not applicable to sugarcane, which is generally grown in flat areas.

Contour Farming and Strip Cropping

Contour farming is generally used for production of annual crops like corn, soybean, and cotton on sloping land. The tillage furrows are designed to follow the contours and be perpendicular to the slopes of the field. This orientation of the rows allows the crop rows to intercept runoff increasing water infiltration into the soil and reducing runoff water and pesticides leaving the field. Use of contour farming requires detailed planning by the grower but once implemented can be readily utilized annually.

Strip cropping involves the use of preplanned rotations of crops planted in equal width strips across a field with the rows of crops oriented perpendicular to the slope, similar to contour farming. At least 50% of the strips in the field consist of a grass or close growing crop which are alternated with a crop with less protected cover. Strip cropping works better in some rotational systems, especially ones that contain a forage crop, than rotations that include only row crops. Strip cropping requires greater managerial effort than other production systems.

Contour farming and strip cropping practices are designed to reduce runoff on sloped fields. These practices are not applicable to flat land as there is no slope to follow and would likely not have the same effect in reducing runoff on flat fields as on sloped fields. These practices are likely not applicable to sugarcane, which is generally grown in flat areas.

Vegetated Ditch Banks (Sugarcane Only)

Establishing and maintaining vegetated ditch banks near sugarcane fields slows movement of water in ditches and reduces runoff. Similar to other practices discussed above that involve strips of perennial vegetation, there are costs associated with establishing and maintaining the vegetated ditch banks. Extension publications recommend controlling grass weeds like johnsongrass, itchgrass, and bermudagrass in ditch banks to prevent them from moving into adjoining sugarcane fields (Orgeron 2022) which would require the use of additional herbicide applications to these areas.

Pick-list of Runoff Management Options

Not all of these agronomic and engineering practices are viable for all users, and therefore, requiring that all growers adopt a fixed set of mitigations would likely be the equivalent of cancelation of atrazine for many growers. For this reason, the Agency is considering adding a "pick-list" to the labels where growers can select some combination of runoff mitigations on land where atrazine is used, in order to reduce runoff of atrazine and the associated environmental risks. Growers would need to select and implement one or more practices from the list on the land on which they intend to apply atrazine for the length of the growing season. The exact number of practices required could be determined based on characteristics of atrazine use. For instance, the number of required runoff reduction practices from the pick-list could vary by the magnitude of risk associated with runoff, with higher requirements for fields located in watersheds with higher concentrations of atrazine. Different numbers of practices could be allowed for different crops and different regions, because atrazine use patterns differ between the various crops where atrazine is frequently used, and within crops, atrazine use patterns differ across the country. More practices could be required if the field is on highly erodible land where runoff is more likely. The number of practices could also be determined by the application rate of atrazine that the grower intends to use, as higher rates will have more risk of runoff – however, allowing growers to use less practices if they use lower atrazine rates will incentivize growers to reduce their rates, and may increase resistance pressure on atrazine, as described above in the section "Impacts of rate reductions on herbicide resistance management".

BEAD expects that growers would select the least burdensome method to achieve the required number of practices necessary to use atrazine. Growers would adopt management practices that are appropriate to their production system, the physical characteristics of each piece of land that they own or lease, or area of the country. The difficulty of adopting runoff mitigations from the pick-list would vary by grower based on their experience with such practices and on the characteristics of their land. Some land may be more adaptable to a particular conservation practice while others may be more challenging. For some growers, the process of achieving the required number of runoff reduction practices may take more than one growing season to implement – and these growers may be unable to use atrazine during this period.

The expectation that growers would choose the most appropriate and least burdensome mitigations does not mean that the cost required of growers to comply with these mitigations would necessarily be small. If the grower is not familiar with the conservation practices, a grower would have to become acquainted with the requirement(s) and the specific practices they choose to pursue to ensure that they are appropriate and effective for their specific land. This may be resource intensive depending on a grower's current management practices, relevant education on such practices, familiarity with how to successfully implement a practice or set of practices, among other factors (Knowler and Bradshaw, 2007; Young and Shortle, 1984). The flexibility offered by a pick-list imposes a higher managerial burden in determining the optimal way to comply with the pick-list. Growers who find the pick-list too difficult to understand will have to use alternative herbicides, facing substantial cost increases and potential yield loss.

Growers may already be utilizing one or more of the conservation practices that reduce runoff in their current production practices. For example, growers may already be utilizing cover crops as part of their production system, and these growers would be able to apply cover cropping toward the required number of practices with negligible impact; however, they may need to adopt additional practices to meet the required number of practices. Some growers may already utilize multiple conservation practices intended to reduce runoff as part of their production systems and achieve the required number of practices with their current management practices. The impact of adopting the labeled conservation measures would impose negligible burden on these growers.

The difficulty of adopting mitigation options also varies depending on the crop. Many of the conservation practices EPA could include on a pick-list are more common in large-acreage field crops, and used more rarely in specialty crop like sweet corn and perennial crops like sugarcane. Agronomic differences in crops will also impact viability of practices. For example, sugarcane is a multi-year crop, and some practices are appropriate for different stages of the crop cycle. Growers may not be able to soil incorporate an atrazine application in the first year of the cropping cycle and may not be able to plant a cover crop in the middle of a sugarcane cropping cycle.

Due to the complexity of a pick-list which differs by crop, region, watershed, and soil type, the pick-list mitigation could be very complicated and would not be easy to adapt to a pesticide label. BEAD understands that a registrant-sponsored online database is being considered. If the atrazine requirements for an area were accessible via an online tool which showed growers the relevant mitigation requirements, this would likely lower the managerial burden of compliance. However, accessing online mitigation in a pick-list format may be new for some growers, and mitigations stored electronically may be difficult to access easily without a reliable internet connection. Utilizing the online tool to determine the mitigations to use on a given field will be an extra step required for growers to undertake prior to making an application. This burden may be especially high for growers in more rural areas with unreliable internet connection and/or growers who are not proficient in internet-based tools.

Impact of Required Number of Practices

The higher the number of practices that the Agency requires growers to adopt in order to use atrazine, the higher the cost for a grower to comply with the mitigation. Higher compliance costs will mean that more growers will find the cost of complying with the mitigation to be greater than the benefits gained from atrazine. These growers will instead have to use alternative herbicides and may face substantially higher pesticide control costs and potentially yield loss.

The feasibility of adoption of other runoff reduction practices may be situational, restricted by crop, location, and grower production practices. Some runoff reduction practices preclude adoption of other practices. The limitations on the feasibility of the adoption of multiple of these practices is discussed below.

Field Corn and Sorghum

As field corn and sorghum are grown across a wide area of the U.S., geography and topography have a large influence on the number of practices that growers can feasibly adopt. For example, growers who farm on hilly terrain would be able to utilize contour cropping or terracing whereas growers who produce corn and sorghum on flat fields would not be able to use contour cropping or terracing.

Field corn and sorghum can both also be produced with irrigation or under dryland (non-irrigated) conditions. In general, corn is generally planted where there is ample natural rainfall or irrigation to supply the water needs of a corn crop, and sorghum is planted in driers areas with lower natural rainfall and less opportunity for irrigation. However, both corn and sorghum can be successfully grown under as dryland or irrigated crops. Growers of irrigated corn and sorghum could utilize irrigation water management practices to reduce atrazine runoff, but this mitigation option would be unavailable to dryland producers. Furthermore, corn and sorghum producers in areas with high natural rainfall or irrigation would be more able to utilize mitigations that require the establishment and maintenance of vegetation other than the crop produced in drier areas including: vegetative filter strips, field borders, grassed waterways, and cover crops. This is because maintaining vegetative cover in vegetative filter strips, grassed waterways, and field borders requires a substantial amount of water, which may not be available or sufficient to maintain these vegetated areas in drier production regions. Furthermore, there are costs associated with irrigation. Growers willing to use irrigation water to maintain vegetative areas would incur these costs. Similarly, the USDA points out that corn and sorghum growers in dry production areas would be unable to utilize cover crops as cover crops deplete soil moisture which is necessary to produce the corn or sorghum crop (USDA OPMP, 2022).

BEAD notes that some of the potential mitigations are mutually exclusive and cannot be used together. For example, a grower utilizing a no-till or conservation tillage production system will not be able to utilize soil incorporation of atrazine, as soil incorporation requires extensive soil disturbance. Also, as soil incorporation of atrazine can only be used during the preplant timing in corn and sorghum, growers would not be able to utilize both soil incorporation as one runoff mitigation strategy while also avoiding pre-emergence applications of atrazine as a second runoff mitigation strategy. Furthermore, growers wishing to utilize banded atrazine applications to meet rate reductions, would find it difficult to utilize no-till or conservation tillage systems, as weed control between the herbicide bands is often accomplished with the use of tillage or cultivation. Finally, corn and sorghum producers would find it difficult to eliminate preemergence atrazine applications and utilize a no-till or conservation tillage system. Corn and sorghum growers using no-till or conservation tillage rely more on herbicides, especially atrazine, for control of early-season weeds, as preplant tillage and cultivation cannot be practiced with no-till and conservation tillage systems.

In a survey of growers and state agricultural Extension specialists (USDA OPMP, 2022), USDA suggests that growers with adequate rainfall, such as growers in the Corn Belt, or growers with irrigation would be able to utilize 3-4 of the runoff mitigation pick-list practices, while dryland corn and sorghum producers in dryer areas, such as the Southern Plains, would only be able to feasibly implement 1-2 of the runoff mitigation pick-list options.

Sweet Corn

Sweet corn production varies considerably from field corn production. Sweet corn is harvested primarily for fresh market sale or for processing into packaged consumer goods such as frozen or canned sweet corn. As sweet corn is managed as a vegetable crop it is often grown in rotation with other vegetable crops, sometimes within the same growing season. Vegetable crops and other specialty crops generally have less herbicide options than major crops like field corn and therefore rely heavily on tillage and cultivation for weed control. This severely limits the ability of growers to produce sweet corn under no-till or conservation tillage. Furthermore, sweet corn has low seedling vigor, meaning stand establishment under the high plant residue conditions characteristic of reduced tillage would severely challenge stand establishment in sweet corn. Similarly, the high levels of plant residue associated with cover crop use, make cover crop utilization in sweet corn unfeasible (USDA OPMP, 2022). Sweet corn operations are generally much smaller than typical field corn or grain sorghum operations – according to the 2017 Census of Agriculture, 45% of sweet corn farms are under one acre in size, while only 12% of field corn farms are under one acre in size (USDA NASS, 2022); that sweet corn fields are smaller than field corn is demonstrated in Table 7. As a result, sweet corn growers have reduced ability to afford expensive structural mitigations like terraces. The practices that could be feasibly implemented by sweet corn growers include field border, grassed waterway, irrigation water management, no preemergence applications, and vegetated filter strips (USDA OPMP, 2022). BEAD expects that a typical sweet corn grower could adopt at most 1-2 of these pick-list runoff mitigations, because of costs associated with the practices or because adopting multiple of these practices would take a large amount of land out of production.

Sugarcane

Sugarcane is a perennial crop grown in very small and specific areas of the U.S. and has much different agronomic management considerations than field corn, sorghum, or sweet corn. In Florida and Louisiana and Texas sugarcane is produced in flat, often precision leveled field, meaning that runoff mitigations, like terracing, strip cropping, grassed waterways, and contour farming are not applicable to sugarcane production. Sugarcane is generally planted in the fall of the year (plant cane) and then managed as a perennial crop for 3-5 years (ratoon cane) before being briefly rotated with another crop before replanting. This perennial production system limits growers' ability to use runoff mitigations like cover crops and soil incorporation. Information provided by the USDA suggests that little irrigation is used in sugarcane in Louisiana and Texas and irrigation water management is not compatible with the way that sugarcane is irrigated in Florida (sugarcane in Florida is irrigated by raising groundwater levels and not through traditional irrigation methods like pivot or furrow irrigation). The USDA also suggests that no-till and conservation tillage systems are not compatible with sugarcane and that field borders and vegetative filter strips are not feasible due to topography and design of sugarcane fields (USDA OPMP, 2022). BEAD concludes that feasible runoff mitigations practices are limited to rate reductions, rainfall timing restrictions, and vegetated ditch banks.

To further illustrate potential challenges associated with the "pick list", see Appendix A for a decision tree for an example grower demonstrating the complexity of adapting their production to potential atrazine mitigation requirements. Additionally, see Appendix B for example scenarios as to how farmer might approach this new mitigation.

In conclusion, even a limited number of specified requirements to reduce runoff could have a substantial impact on some, if not many, users of atrazine due to the difficulty in implementing them across the range of fields and agronomic conditions. However, allowing growers to choose from among a suite of options to reduce runoff would reduce impacts and is likely to allow most users to adapt their production practices. Initial costs, though, will likely be high for many growers as they will need to decide how best to achieve the necessary requirements to be able to apply atrazine and this will likely vary field to field. As long as runoff reduction measures remain consistent overtime, growers will become familiar with the practices and pick lists for runoff control will become less burdensome.

Distributional Considerations

The mitigations which EPA is considering requiring in order to reduce atrazine runoff may disproportionally affect small farmers. Many of the structural mitigations, such as land terracing, have high fixed costs to install. Large operations may find these mitigations less burdensome to adopt compared to small farms. Others of these mitigations are more easily adoptable on large farms and over large acreages compared to farms with small acreages; vegetated filter strips, for example, take up a larger proportion of a smaller field compared to a larger field. The agronomic mitigations may also be more easily adopted by larger and more profitable operations. For instance, changes to tillage practices or adoption of cover crops may require specialized equipment, which larger farms are more likely to already have, and which larger farms may able to purchase more easily. Runoff reduction practices which require substantial managerial effort, such as strip cropping, are likely to be more burdensome for smaller operations and part-time farmers, and less burdensome for larger and more technologically sophisticated operations. According to the 2012 Census of Agriculture, about one-third of all agricultural operations have only one operator (USDA NASS, 2022).

If these mitigations are too burdensome, some growers, particularly smaller farms and farms facings financial constraints, may be forced to use other herbicides, as described in the first section, and may suffer higher weed control costs or potentially worse weed control.

Mitigation Impacts to Other Atrazine Use Sites

In addition to mitigation on the four major crop use sites above, EPA is also considering imposing mitigations on other agricultural and non-agricultural atrazine use sites. Other agricultural use sites include guava, macadamia, and fallow periods in wheat rotations. Non-agricultural use sites include turfgrass, nursery and ornamentals, and rights-of-way excluding roadsides.

In these use sites, EPA is considering prohibiting aerial applications of atrazine, restricting applications before rainfall, and restricting applications to saturated soils as nationwide runoff mitigation measures, which would impact all atrazine use sites. EPA is only considering a pick-list mitigation system for the four major crop use sites, and is not considering a pick-list system for the other agricultural and non-agricultural use sites.

Prohibition of Aerial Applications

BEAD does not have usage information on aerial applications to other agricultural or non-agricultural use sites. Impacts to aerial users are expected to be similar to aerial users in the four major crop use sites, as described above. Aerial users would need to apply atrazine via ground equipment (which may not be feasible for some circumstances, or may require the purchase of new equipment), or else growers will need to replace atrazine with alternative herbicides, possibly facing cost increases or reduced weed control. Based on discussions with industry regarding common production practice used in turf, aerial application would not be a commonly used application method (Reynolds, personal communication), so any potential mitigations should have little impact on users of atrazine in turf.

No Applications to Saturated Soils

Applicators typically avoid driving equipment in fields when the soils are saturated to prevent damage to fields, so impacts are expected to be minimal for use sites where sprayers are driven across soil. In established turf and in other use sites with vegetated or firmer surfaces, sprayers could be driven across areas that are wetter than bare ground/newly planted/establishing turf. If an application is needed and soils are saturated, applicators would need to apply a product that allows aerial application or else delay the application. The impact to users would also vary by soil textural class, as soils with greater clay content will retain water longer than sandier soils, possibly affecting the potential application window for atrazine.

No Applications Before Rainfall

Similar to the impacts of restricting applications before rainfall on row crops, this restriction on other use sites may limit the available hours applicators are able to apply atrazine and could delay time-sensitive herbicide applications and would vary based on regional specific weather patterns (as described in the row crop section). Additionally, a restriction could interfere with activation of atrazine which could result in poor weed control. To prevent loss of weed control, an applicator could choose to use alternative herbicides that do not have the rainfall restriction. Additionally, a restriction that limits application shortly before any rainfall could prevent activation and disrupt an applicator's ability to control weeds in a timely manner. Like impacts to row crops, to minimize impacts to applicators of other use sites, restrictions would need to be defined in a manner that account for rains that are unlikely to produce a runoff event.

CONCLUSIONS

The Environmental Protection Agency (EPA or the Agency) is reconsidering a portion of the Atrazine Registration Review Interim Decision issued in September 2020 related to potential ecological off field risks to aquatic plant communities associated with the agricultural uses of atrazine. This memorandum summarizes information from past assessments of the benefits of atrazine, considers whether those benefits have changed, and assesses impacts of potential risk mitigation for atrazine in field corn, sweet corn, sorghum, and sugarcane, the four major agricultural use sites for atrazine.

Atrazine is widely used in field corn, sweet corn, sorghum, and sugarcane – over half of all acres planted of each of these crops are treated with atrazine each year. Atrazine is an important herbicide in these crops because it is economical, has a flexible use pattern, long residual herbicidal activity and is effective against a broad spectrum of weeds. Atrazine is an important tool in herbicide resistance management, both in controlling weeds resistant to other herbicides and maintaining the effectiveness of other herbicides to control weeds.

The benefits of atrazine are high in these four crops, increasing grower net operating revenue by up to $30 per acre in field corn, up to $52 per acre in sweet corn, and up to $16 per acre in sorghum compared to the next best alternative weed control options. Atrazine is especially beneficial for Southern growers, who may not have efficacious alternatives to atrazine for regional weed pressures. In sugarcane, atrazine increases grower net operating revenue by up to $13 per acre compared to the next best alternative weed control options. These benefits are estimated as the impact on growers if atrazine were not available – without atrazine, growers would face up to a 61% decrease in net operating revenue in field corn, up to complete net revenue loss in sweet corn, up to a 67% decrease in net operating revenue in sorghum, and up to a 17% decrease in net operating revenue in sugarcane.

The Agency is considering mitigation measures to reduce risks due to runoff from the use of atrazine, including limiting when and how atrazine can be applied, reducing maximum use rates, and requiring the adoption of engineering and agronomic practices that reduce runoff. The Agency could require growers adopt some or all of these mitigation measures, or the Agency could require a "pick-list" where growers can select some combination of runoff mitigation measures to reduce runoff to continue using atrazine. These practices could include structural changes to the field, such as terraces or vegetated filter strips, or these could be changes to grower agronomic practices, such as using lower rates of atrazine or growing cover crops. The number of practices required for growers to adopt could be determined by crop, region, soil erodibility, watershed, and the annual atrazine rate used. The impact on growers of complying with individual potential mitigation measures are:

- Application rate reductions would cause growers who currently use higher than a new maximum rate to reduce their rate or seek alternatives to atrazine. Lower rates could reduce weed control which would likely complicate herbicide resistance management by increasing selection pressure for atrazine-resistant weeds and making atrazine less effective as a tool to control weeds that are resistant to other herbicides. Growers could compensate by using additional herbicides or replacing atrazine entirely. The larger the rate reduction the more impactful the restriction will be for growers, thereby making it more difficult for growers to find a way to continue to use atrazine effectively. Further, the larger the rate reductions the more growers will have to adjust their atrazine use in response. For example, reducing maximum annual atrazine rates to one-pound per-acre in field corn would impact 30% of current acres treated nationally, and 60% of current acres treated in the Southern U.S. The magnitude of impacts vary both between crops and between regions within crops. Regionally, rate reductions are likely to be less feasible for growers of field corn and sweet corn in the Southern U.S. and for sugarcane growers in Florida, who apply at higher rates.

- Prohibiting aerial applications of atrazine when soil is saturated, and restricting applications of atrazine prior to forecasted rainfall would together limit the ability of growers to use atrazine from the start of forecasted rain until the ground is no longer saturated. The limitation on application prior to forecasted rainfall could be particularly impactful because it may prevent timely atrazine applications, even if precipitation does not actually occur. The longer the restricted interval prior to forecasted rainfall, the more difficult it would be for growers to use atrazine. If weed control is necessary in that window of time, growers would need to use alternatives to atrazine, facing impacts as described above, or else face yield losses. BEAD notes that many growers would not apply before heavy rainfall which is likely to produce runoff, as this could result in poor weed control. If applications of atrazine are not restricted prior to rainfall which is unlikely to produce runoff (light rain), then the rainfall restriction is less impactful.
- Eliminating preemergence applications eliminates a common application timing for atrazine. Atrazine is frequently used prior to crop emergence in sorghum and field corn production, and to a lesser extent in sweet corn. Some growers who currently use atrazine prior to crop emergence can move these applications after crop emergence, but may face cost increases to replace weed control prior to crop emergence. Growers who use atrazine twice a year would need to replace atrazine and thus may face cost increases or a reduction in weed control.
- Requiring soil incorporation of atrazine instead of surface-applied atrazine may have low impacts on growers depending on their atrazine tank-mix partners and application timing. Soil incorporation is a form of tillage and is only viable for preplant applications because it would displace seeds after planting or damage the crop after emergence. This means that soil incorporation is not compatible with other mitigation measures such as eliminating preemergence applications or requiring no-till or conservation tillage systems. Soil incorporation also has costs associated with tillage and additional application costs if tank-mix partners cannot be soil incorporated.
- Requiring no-tillage or reduced-tillage production would impose high costs on producers of sweet corn or sugarcane production because tillage is important for weed control in sugarcane, and is unlikely to be infeasible in sweet corn because the crop has low seedling vigor and does not establish well in no- or reduced-till fields. For corn and sorghum growers, switching to no-till or reduced tillage systems would likely require investment in new equipment or retrofitting existing equipment for managing the crop under high-plant residue conditions. Also, as no-till and reduced tillage systems rely heavily on herbicides for early-season weed control, these systems may increase the impact to the grower of other mitigation measures such as reducing application rates or prohibiting preemergence applications.
- Requiring cover crops would raise production costs since it involves establishing and removing a crop that produces little or no revenue. Cover crops can be incorporated into corn and sorghum production systems that have adequate natural rainfall or are irrigated (e.g., the Corn Belt and Southeast) but are less feasible in dryland areas with low rainfall

(e.g., the Plains states). Cover crops are not feasible for use with sweet corn due to the low seedling vigor of sweet corn in fields with cover crop residues, similar to no-till and reduced-till systems, and are not feasible for use with sugarcane due to the perennial production system.

- Requiring irrigation water management requires managerial expertise and may require purchasing specialized equipment, which may be costly. Growers who do not irrigate cannot conduct irrigation water management.
- The impact of requiring vegetative filter strips (VFS), field borders, grassed waterways, contour buffer strips and contour terracing, and grass ditch banks is dependent on the size and topography of the field and on the size of the required buffer. As buffers take land out of production, BEAD anticipates that growers could face substantial loss of cropped land and thus loss of revenue. Growers with smaller fields and growers of crops that are typically grown in small fields, particularly sweet corn and sugarcane, will lose a larger portion of their field to buffers compared to growers with large fields. These measures require capital investments in land modification. Establishment costs for VFS, for example, range from $165-$927 per acre of VFS and maintenance costs range from $40-$240 annually per acre of VFS. Contour terracing may be more expensive than other kinds of buffers, as they require the creation of semi-permanent ridges. Contour buffer strips and terracing are not feasible where crops are produced on flat land and are not applicable to sugarcane production.
- Requiring contour farming or strip cropping will impose a variable burden depending on field slope. These practices may be burdensome but feasible for production of annual crops on sloped fields, requiring substantial managerial effort and purchasing specialized equipment. However, contour farming and strip cropping are likely impossible on sugarcane or other crops produced on flat fields.

Compared to specifying a fixed set of mitigations, which would likely represent an effective cancelation of atrazine for many users, a pick-list of mitigation measures gives growers flexibility, allowing growers to select the least burdensome method to achieve the required number of practices necessary to use atrazine. The impacts of complying with a required pick-list depend on the grower’s current agronomic production practices, region of the country, the watershed their field is located in, and whether the grower is already undertaking any of the measures described on the mitigation pick-list. Additionally, managerial effort is higher with a pick-list than a specific list of mandatory requirements. Some runoff reduction practices preclude adoption of other practices. How burdensome this pick-list is for growers depends on how many runoff reduction practices are required for growers to use atrazine. It may be harder for sweet corn and sugarcane growers to adopt multiple practices from the pick-list compared to field corn and sorghum growers. The potential mitigations may also be more burdensome for small and lower-income farmers. Growers for whom achieving the required number of required practices is too burdensome would have to replace atrazine with other herbicides and would lose the benefits of atrazine as described previously.

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Appendices

The two appendices for this document are designed to provide illustrations of the kinds of challenges and the range of impacts that growers may face as they adapt their current atrazine-containing weed control programs to meet the requirements of the potential mitigation. These examples are not designed to be comprehensive or applicable to all growers, but rather examples of the challenges that particular growers in particular circumstances may face complying with the potential mitigation.

Appendix A is designed to illustrate the managerial challenge of complying with a pick-list. As described above, BEAD expects a pick-list to be lower impact than universally required mitigations, because growers can choose to adopt the mitigations which best fit their particular circumstance. However, the pick-list selection process has higher managerial effort requirements than universally required mitigations. Appendix A illustrates the management challenges a grower may face as they attempt to comply with the requirements to continue to use atrazine. It also demonstrates that even with a pick-list, the set of options a grower may feasibly choose from may be exceedingly limited.

In Appendix B, BEAD creates seven hypothetical growers, each with unique crops, locations, field conditions, and atrazine requirements. Based on assumptions about the pick-list each grower would face, BEAD estimates the way each grower might choose to comply with the mitigation, including whether the grower chooses to continue to use atrazine, change their atrazine use pattern or rate, or adopt additional mitigations in order to maintain their current use pattern. BEAD also qualitatively describes how impactful the mitigation will be for the grower to adapt to – with higher costs, more mitigations, and more substantial changes to a weed management program equating to a higher compliance burden.

Appendix. A Thought process of a farmer working through proposed mitigation options. This scenario represents a progressive corn farmer in Georgia who farms on highly erodible soils. Note that this thought process does not include spray drift considerations (e.g., windspeeds) at this time; they would add more complexity. Additionally, the farmer will need to ask these questions for each individual field since these mitigations will be tailored to individual fields.

Q1. Will I need to adjust my historic weed control program (i.e., do I usually apply more than 2 lbs ai / year)?

→ **Yes,** I apply more than 2 lbs; therefore, I likely need to supplement my weed control program to account for the lower annual rate of atrazine.
No, I use less than 2 lbs; therefore, my weed control program is not likely to be impacted by the reduced annual rate.

Q2. What Region/HUC is my field in and the likelihood of erosion to occur in my field to determine my mitigations?

→ To answer this question – you need to follow up with:
2a. What is my region?
2b. What watershed / atrazine concentration does my field fall within?
2c. Do I have a field with highly erodible soil?

2a. What is my region?

→ Regions are defined on the label. Georgia is Region 1 (R1).

2b. What HUC is my field in? Do I have a field that is in a watershed with a high [A2], medium [A1], or low [A0] concentration of atrazine?

→ A Syngenta sponsored website will determine which HUC a field is in based upon the location of the field. HUCs are based on predicted concentrations of atrazine [A] in a watershed and the website will tell you which category your field falls within; however, the grower must have internet access prior to the application.

2c. Do I have a field with highly erodible soil?

→ Farmers should determine the erodibility of their fields. Select from options erodible soil (HE) or non-highly erodible (NHE)[1].

Answers for Q2 inform the required mitigations. Below shows the resulting number of mitigation options a grower in Region 1 must implement with the additional consideration of application rate (i.e., as lower rates will allow for the adoption of fewer runoff conservation measures).

Field location & characteristics:	R1/[A0]/HE or NHE	R1/[A1]/HE		R1/[A1]/NHE		R1/[A2]/HE		R1/[A2]/NHE	
Rates (lbs/year):	≤2.0	<1.2	>1.2	< 1.2	>1.2	<0.8	>0.8	< 0.8	>0.8
Number of required runoff conservation measures needed to adhere to the label:	**0** Continue to Q4	**2**	**4**	**1**	**2**	**2**	**4**	**1**	**2**

Q3. Considerations for the **runoff conservation practices (RCP).** The farmer battles Palmer amaranth and needs the full 2 lbs of atrazine per acre after crop emergence. The grower is in the watershed [A1] with highly erodible soils and **will need to do 4 RCP.** For the purpose of this exercise, it is laid out as if the grower is planning for the coming year (winter) and needs to adapt current practice to be able to apply atrazine, as well as the grower is thinking about future planting seasons. Practices that are greyed out are not normal practices and likely require time to plan for adoption; blue font indicates where the farmer meets the requirement; and red font indicates a partial fulfilment but does not get credit for the practice.

[1] Highly erodible lands contain soils that have an erodibility index of eight or more, https://www.ecfr.gov/current/title-7/subtitle-A/part-12/subpart-B/section-12.21.

Q3. continued

RCP1: Do I need a pre-emergence (PRE) application?

- Yes → 0
  - Do I need a PRE rate greater than 1.6 lbs/A?
    - Yes → Need to alter weed control as PREs cannot exceed 1.6 lbs
    - No → No change needed to herbicide program
- No → 1

Note that this practice is incompatible with RCP2

RCP2: Can I incorporation atrazine into the soil at a depth of 2.5 cm?

- Yes → 1
- No → 0

Note that this practice is incompatible with RCP1 and may be incompatible with RCP3.

RCP3: Is my normal practice to be no till or reduced till, such that >30% of soil is covered?

- Yes → 1
- No → 0
  - Can I convert to no-/reduced till in the **future**?
    - Yes → 1
    - No → 0

Yes, but I will need to invest in new planting equipment.

Note that this practice may be incompatible with RCP2 and RCP4.

RCP4: Am I able to plant into a cover crop residue?

- Yes → 1
- No → 0
  - Can I plant a cover crop in the fall for **future** years?
    - Yes → 1
    - No → 0

Yes, but I will need to determine, what cover crop and how I will kill it in the spring. It may necessitate new equipment or tillage.

Note that this practice may be incompatible with RCP3.

RCP5: Irrigation water management – is my field irrigated?

- Yes
  - Do I already have special equipment to control/ monitor the amount of water applied to my field?
    - Yes → 1
    - No
      - Can I install the necessary equipment for **future** use? → With substantial investment, the field may be converted to irrigation depending on the accessibility of water in my area. With moderate investment, irrigation equipment may be upgraded.
- No → 0
  - Can I convert my field for irrigation for **future** use? → With substantial investment, the field may be converted to irrigation depending on the accessibility of water in my area. With moderate investment, irrigation equipment may be upgraded.

RCP6: Do I have an existing vegetative filter strip?

- Yes
  - What size is it and what is my hydrological soil group (HSG)?
    - My HSG is A or B
      - Is the strip ≥ 30 ft?
        - Yes → 1
        - No → 0 → Can I make a suitable filter strip for **future** use?
    - My HSG is C or D
      - Is the strip ≥ 100 ft?
        - Yes → 1
        - No → 0 → Can I make a suitable filter strip for **future** use?
- No → 0 → Can I make a suitable filter strip for **future** use?

Can I make a suitable filter strip for **future** use? → Yes, but it will require me taking land out of production and includes incurring cost to establish and maintain the filter strip.

RCP7: Do I have an existing field border?

- Yes → 1
- No → 0
  - Can I convert to land to a field border in the **future**?
    - Yes → 1
    - No → 0

Yes, and I may not have to take land out of production, but it will require establishing and maintaining the border.

RCP8: Do I have an existing grassed waterway?

- Yes → 1
- No → 0
  - Can I convert to land to a field border in the **future**?
    - Yes → 1
    - No → 0

Maybe, I need to see if my field is conducive. If it is, it will require me taking land out of production and includes incurring cost to establish and maintain waterway.

RCP9/10: Do I already have contour buffer strips or terraces?

- Yes → 1
- No → 0
  - Can I create either of these features in the **future**?
    - Yes → 1
    - No → 0

Maybe, I need to see if my field is conducive. If it is, it will require me taking land out of production and includes incurring cost to establish and maintain.

RCP11/12: Do I already plant along the contours or have strip crops?

- Yes → 1
- No → 0
  - Can I adopt either of these practices in the **future**?
    - Yes → 1
    - No → 0

Maybe, it will require some planning, but contour farming is more likely than strip cropping.

Based on current practices, this farmer only achieved 3 of the 4 RCP. This grower will need one more RCP for this year, if feasible; otherwise, they will need to make significant adjustments to their herbicide program. Given that the many RCP require extensive planning, this grower may be most likely to eliminate the PRE or adopt a lower rate and alter their weed control program. With some effort and planning, it is likely the grower will be able to adopt an additional practice for the following year. Note that this a hypothetical scenario and that every field this grower farms will need to be walked through this process.

To build on this scenario, we will say that the GA farmer decides that, since they are not able to achieve 4 RCP with current practices, they decide to **forego a PRE** application as opposed to applying a reduced rate. Now that the grower has the required number of RCP in place, they are ready to apply.

However, there are **two more requirements that must be met**: prohibition of applications to saturated soils and predicted weather for rainfall restrictions

Q4. Is my soil saturated? →

Yes – DO NOT APPLY (note, aerial has been cancelled; therefore, aerial applications are not an option to apply to saturated soils)

No – proceed to Q5.

Q5. Is rain forecasted in the next 48 hours for my area? →

Yes – DO NOT APPLY

No – Application can occur

If the grower answers yes to either question 3 or 4, applications cannot be made, despite planning and potentially investing in structural modifications to the field.

Appendix B: How Example Growers May Respond to Potential Atrazine Mitigations

To illustrate the requirements of complying with a pick-list, BEAD assesses how some growers could comply with a potential pick-list.

Table A. Potential Pick-List Mitigation Practices
No pre-emergence applications
30 ft (A & B soils) or 100 ft (C & D soils) vegetative filter strip
Cover crop
Contour buffer strips
Terraces
Field border
Grassed waterway
Irrigation water management
Contour farming
Strip cropping
Soil incorporation to a depth of 2.5 cm
No tillage and reduced tillage (>30% of soil covered)

All growers have to make a decision about their weed control program for the upcoming season many months before the growing season begins. Therefore, each grower will likely decide whether or not to use atrazine many months before atrazine is actually applied. This decision compares the grower's expected revenue with the use of atrazine, including required mitigations, and including the potential for rain preventing the grower being able to apply atrazine at the desired timing, against the grower's expected revenue without the use of atrazine, including any cost increases from the alternative weed control program (including relevant weather-related challenges) and potential yield loss resulting from poor weed control. If the grower decides to adopt runoff reduction practices in order to use atrazine, but rain or other conditions prevents the grower from applying atrazine, the grower still has to bear the costs of the runoff reduction practices.

BEAD does not expect the precipitation restrictions to substantially restrict the grower's ability to use atrazine. Growers are unlikely to apply to atrazine before large rainfall events that would cause runoff of atrazine from the field, and so the restriction is unlikely to prevent growers from using atrazine.

Grower 1: Typical Southern Field Corn Grower. Moderate Impact.

Grower Characteristics

Scenario: Arkansas grower. Irrigated field corn, conventional tillage. Atrazine normally applied once prior to crop emergence at 1.65 lbs a.i./acre (regional average). Ground application.

Per label information, field is in a high concentration watershed (List 2) on non-highly erodible land.

Based on a potential label Grower 1 will need to comply with the following mitigation requirements:

- Soil saturation prohibition
- Aerial application prohibition
- Precipitation restriction - prohibiting application of atrazine containing products during rain or when a storm event likely to produce runoff is predicted
- Do not apply more than 2.0 lb ai/A per year.
- At an application of 1.0 lb ai/A/y or less, **one** runoff reduction practice must be present from **Table C.**
- At an application above 1.0 lb ai/A/y, **two** runoff reduction practices must be present from **Table C.**

Grower 1 has to make a decision about their weed control program for the upcoming season many months before the growing season begins. Therefore, Grower 1 will likely decide whether or not to use atrazine many months before atrazine is actually applied. This decision compares the grower's expected revenue with the use of atrazine, including required mitigations, and including the potential for rain preventing the grower being able to apply atrazine at the desired timing, against the grower's expected revenue without the use of atrazine, including any cost increases from the alternative weed control program (including relevant weather-related challenges) and potential yield loss resulting from poor weed control. If Grower 1 decides to adopt runoff reduction practices in order to use atrazine, but rain or other conditions prevents Grower 1 from applying atrazine, the grower still has to bear the costs of the runoff reduction practices. BEAD previously assessed the impact of replacing atrazine in field corn production in the South and found that growers replacing atrazine prior to crop emergence may face a cost increase of $7 per acre (Tindall and Smearman, 2019).

BEAD does not expect the precipitation restrictions to substantially restrict the grower's ability to use atrazine. Growers are unlikely to apply to atrazine before large rainfall events that would cause runoff of atrazine from the field, and so the restriction is unlikely to prevent growers from using atrazine.

Since Grower 1 is using substantially over 1.0lbs of atrazine per acre annually and does not have any runoff reduction practices on their field, Grower 1 has four options:

1) Choose to not use atrazine, suffering cost increases of up to $7 per acre and possibly not be able to control important herbicide-resistant weeds, resulting in substantial losses in yield and net operating revenue.

2) Change from applying atrazine prior to crop emergence until after crop emergence and adopt no additional runoff reduction practices.
3) Reduce their rate substantially and adopt one runoff reduction practice from Table A.
4) Use their intended application rate and adopt two runoff reduction practices from Table A.

The grower will choose the lowest cost of these three options.

Option 2 could be costly as it would involve a substantial reduction in the normal application rate, from 1.65lbs ai/A to 1.0lbs ai/A. Growers use atrazine rates effective on targeted weeds, and at a substantially lower rate the grower may lose control of targeted weeds, e.g., multiple-herbicide-resistant Palmer amaranth. The grower would need to add a tank mix partner with atrazine and the additional cost may be nearly the same as a complete change in herbicides.

The grower will likely not choose to eliminate applications prior to crop emergence (Option 3) because this application timing may be needed to control herbicide-resistant Palmer amaranth.

For Option 4, likely runoff reduction practices for this grower would include irrigation water management, cover crops, or vegetated filter strips (VFS) as these would likely be the least burdensome to implement for this field. Because the grower is on non-highly erodible land, the land may be too flat to implement contour buffer strips, terraces, contour farming, grassed waterways or strip cropping which require sloped fields. The grower is less likely to choose no-till because this may require purchasing specialized equipment. The grower might be able to adopt soil incorporation, depending on whether they have the equipment to incorporate herbicides, what tank mix partners they plan to use, and whether the application is before planting or in the window between planting and crop emergence. If the grower wants to adopt soil incorporation but plans to use a tank mix partner that cannot be incorporated, they would need to make a separate pass through the field to apply atrazine which requires extra fuel and time. These mitigations may be costly to adopt in terms of resources and managerial effort. VFS in particular may result in growers losing the ability to profitably produce on a portion of their field and may interfere with irrigation practices.

Because rate reductions are not feasible for Grower 1, this grower chooses between using an alternative to atrazine (Option 1, facing cost increases of $17/acre and potentially losing the ability to control herbicide-resistant Palmer amaranth), or adopting the two cheapest mitigations (Option 3). For the purposes of this hypothetical example, Grower 1 finds the lowest cost response to the new atrazine mitigations to be adopting irrigation water management and cover crops. Because the grower has to adopt some new practices, which will have costs to the grower, BEAD finds these mitigations to have a “moderate” impact.

Grower 2: Corn Belt Field Corn Grower. Low-Moderate Impact.

Scenario: Iowa grower. Non-irrigated field corn, reduced tillage. Atrazine normally applied once prior to crop emergence at 1.24 lbs a.i./acre (regional average). Ground application.

Per label information, field is in a high concentration watershed (List 2) on non-highly erodible land.

Based on a potential label, Grower 2 will need to comply with the following mitigation requirements:

- Soil saturation prohibition
- Aerial application prohibition
- Precipitation restriction
- Do not apply more than 2.0 lb ai/A per year.
- At an application of 0.625 lb ai/A/y or less, **one** runoff reduction practice must be present from **Table A.**
- At an application above 0.625 lb ai/A/y, **two** runoff reduction practices must be present from **Table A.**
- Do not apply more than 1.2 lb ai/A for pre-emergence applications.

Like Grower 1, Grower 2 has to make a decision about their weed control program for the upcoming season, and about adopting runoff reduction practices, many months before the growing season begins. Grower 2 is using 1.24lbs ai/A, which is only slightly over the maximum preemergence rate, and so BEAD expects this grower may be able to reduce their rate to the 1.2lb ai/A threshold without significantly reduced weed control. If Grower 2 can reduce the rate of atrazine, the grower will not face any additional burden as a result of the preemergence rate restriction.

Grower 2 is now using 1.2 lbs of atrazine per acre annually, which is substantially over 0.625lbs of atrazine per acre annually. At this rate, Grower 2 would need two runoff reduction practices, but is already utilizing one runoff reduction practice. Grower 2 has four options:

1) Choose to not use atrazine resulting in cost increases of up to $8 per acre, equivalent to a 4% decrease in net operating revenue (Tindall and Smearman, 2019).
2) Reduce their rate substantially and adopt no additional runoff reduction practices from Table A.
3) Change from applying atrazine prior to crop emergence until after crop emergence and adopt no additional runoff reduction practices.
4) Keep the preemergence application and adopt an additional runoff reduction practice from Table A.

BEAD expects that Grower 2 will not be able to sufficiently reduce their atrazine rate as their intended rate (1.24lbs ai/A/y) is almost double the reduced rate (0.625lbs ai/A/y).

For Grower 2 to keep their pre-emergence application, they need two runoff reduction practices but already use reduced tillage, so they would need to adopt one additional runoff reduction practice. Potential practices include cover crops, grassed waterways, and possibly switching to postemergence atrazine application. These mitigations may be costly to adopt in terms of resources and managerial effort – for instance, grassed waterways have establishment costs and take land out of production, as described above. The grower will weigh the costs of these mitigations against the loss of up to $28 per acre, and choose the least burdensome option

For the purposes of this hypothetical example, Grower 2 finds that adopting grassed waterways is less costly than not having atrazine prior to crop emergence. Grower 2 therefore chooses to adopt grassed waterways and continues to use atrazine at 1.2lbs/A prior to crop emergence. Because the grower has to adopt an additional runoff reduction practice, BEAD concludes that the grower will face a low-moderate burden.

NB: On highly erodible land, this goes from low-moderate burden to moderate-high burden. The grower will most likely switch from using atrazine preemergence to using atrazine after crop emergence, and still need two more practices. This burden will not be as high if the grower is already engaging in erosion control measures suited for highly erodible land like contour farming.

Grower 3: High-Rate Southern Field Corn Grower. Moderate Impact.

Scenario: Georgia grower. Irrigated field corn with irrigation management, reduced tillage, 75-foot vegetative filter strip (VFS). Atrazine normally applied once after crop emergence at 2 lbs a.i./acre (higher than regional average). Ground application.

Per label information, field is in a high concentration watershed (List 2) on highly erodible land, on hydrologic group C soils.

Based on a potential label Grower 3 will need to comply with the following mitigation requirements:

- Soil saturation prohibition
- Aerial application prohibition
- Precipitation restriction
- Do not apply more than 2.0 lb ai/A per year.
- At an application of 0.8 lb ai/A/y or less, **two** runoff reduction practice must be present from **Table A.**
- At an application above 0.8 lb ai/A/y, **four** runoff reduction practices must be present from **Table A.**
- Do not apply more than 1.6 lb ai/A for pre-emergence applications.

Grower 3 is currently using the maximum allowed atrazine rate after crop emergence. Grower 3 is already utilizing three runoff reduction practices – reduced tillage, irrigation water management, and no preemergence applications.

Under the potential mitigation, Grower 3 would have three options:

- Grower 3 could choose to not use atrazine, suffering cost increases of up to $10 per acre and possibly not be able to control important herbicide-resistant weeds, resulting in substantial losses in yield and net operating revenue.
- Grower 3 could continue using their current rate and adopt one additional runoff reduction practice
- Grower 3 could lower their rate and adopt no additional runoff reduction practices
- Grower 3 could switch from atrazine to using another herbicide

BEAD assumes that atrazine is highly important for Grower 3 and therefore the grower will try to adopt mitigations to use their current rate of atrazine. Grower 3 already has a 75-foot vegetative filter strip and BEAD expects this grower will expand their current vegetative filter strip to 100 feet in order to continue using atrazine. This grower will incur costs to establish and maintain the additional filter strip and will need to take land out of production. Because the grower will need to pay to expand their buffer and will lose productive land, BEAD concludes that Grower 3 will face a moderate burden as a result of these mitigations.

NB: If any of the following grower characteristics change, the burden may increase from ***moderate*** *to* ***high****:*

- *Grower 3 uses the full rate atrazine preemergence*
- *Grower 3 does not already have the ability to irrigate*
- *Grower 3 does not already use contour cropping*
- *Grower 3 does not already use reduced tillage*
- *Grower 3 is using two applications of atrazine per season at over 1lb per acre*
- *Grower 3 cannot easily incorporate vegetative filter strips*

In any of these cases, BEAD expects Grower 3 may need to substantially change their herbicide control program and may face increased herbicide costs from replacing atrazine with an alternative herbicide of up to $10 per acre (Tindall and Smearman, 2019) and may be unable to control important herbicide-resistant weeds.

Grower 4: High-Rate Corn Belt Field Corn Grower. Moderate Impact.

Scenario: Iowa grower. Non-irrigated field corn, reduced tillage. Atrazine normally applied once prior to crop emergence at 2.0 lbs a.i./acre (maximum rate). Ground application.

Per label information, field is in a lower concentration watershed (List 1) on highly erodible land.

Based on a potential label Grower 4 will need to comply with the following mitigation requirements:

- Soil saturation prohibition
- Aerial application prohibition
- Precipitation restriction
- Do not apply more than 2.0 lb ai/A per year.

- At an application of 1.0 lb ai/A/y or less, **two** runoff reduction practice must be present from **Table A.**
- At an application above 1.0 lb ai/A/y, **four** runoff reduction practices must be present from **Table A.**
- Do not apply more than 1.6 lb ai/A for pre-emergence applications.

Grower 4 is currently using the max rate prior to crop emergence. Under the potential mitigation, this would not be allowed. Grower 4 would have multiple options:

- Grower 4 could switch from atrazine to other herbicides, facing a cost increase of up to $8/A, equivalent to a 4% decrease in net operating revenue (Tindall and Smearman, 2019).
- Grower 4 could choose to switch from using atrazine preemergence to using atrazine after crop emergence and adopt two additional runoff reduction practices
- Grower 4 could reduce their preemergence atrazine rate to 1.6 lbs ai/A and adopt three additional runoff reduction practices.
- Grower 4 could reduce their atrazine rate to below 1.0 lbs ai/A and adopt one additional runoff reduction practice.

In this example, Grower 4 is using 2.0lbs of atrazine preemergence because they need the full rate to effectively control the spectrum of weeds present in their fields and will therefore be unable to reduce their atrazine rate. So this grower will have to choose between moving atrazine adopting three additional mitigation practices and not using atrazine.

To get three additional mitigation practices, this grower could switch to postemergence atrazine applications, which may increase preemergence weed control costs. Being on highly erodible, land Grower 4 could also likely adopt cover crops and grassed waterways as mitigation measures. In this example, it is easier for Grower 4 to suffer the $8/A increase in cost replacing atrazine with alternative herbicides than it is to adopt these mitigations.

Because Grower 4 faces a cost increase to replace atrazine, BEAD characterizes the impact of the potential mitigation on this grower as “moderate”.

NB: Any grower in any region using atrazine at or the maximum rate preemergence in a highly erodible soil may face these impacts. Maximum rates are more common in the South than in the Northern regions.

Grower 5: Dryland Sorghum Grower. Moderate-High Impact

Scenario: Kansas grower. Non-irrigated sorghum, reduced tillage. Atrazine normally applied once prior to crop emergence and once after crop emergence, at a rate of 1.0lbs a.i./acre both applications. Ground applications.

Per label information, field is in a lower concentration watershed (List 1) on highly erodible land.

Based on a potential label Grower 5 will need to comply with the following mitigation requirements:

- Soil saturation prohibition
- Aerial application prohibition
- Precipitation restriction
- Do not apply more than 2.0 lb ai/A per year.
- At an application of 1.0 lb ai/A/y or less, **two** runoff reduction practice must be present from **Table A.**
- At an application above 1.0 lb ai/A/y, **four** runoff reduction practices must be present from **Table A.**
- Do not apply more than 1.6 lb ai/A for preemergence applications.

Grower 5 is using 2.0lbs of atrazine per year, and so will need to make a choice:

- Reduce annual atrazine usage below 1.0lbs ai/A/y, and adopt one more runoff reduction practices by either using two lower rate applications, one preemergence and one postemergence or eliminating either the preemergence or postemergence application.
- Keep the current rate and adopt three additional runoff reduction practices.
- Replace atrazine with an alternative herbicide, facing cost increases of up to $16/A, equivalent to a 67% loss in net operating revenue (Tindall and Sells, 2019).

Grower 5 would have a difficult time adopting an additional three runoff reduction practices because of their dryland production system.

Grower 5 could choose to replace their preemergence atrazine application with another herbicide, while keeping the postemergence application. Eliminating the preemergence application counts as a runoff reduction practice, as does the no-till system the grower is already using, together satisfying the two runoff reduction practices requirement. Grower 5 would face an increase in herbicide control costs of $8 per acre, equivalent to a 33% decrease in net operating revenue (Tindall and Sells, 2019).

In this example, Grower 5 would choose to replace one of their two applications of atrazine with an alternative herbicide program. Because this would result in increased herbicide costs equivalent to a 33% decrease in net operating revenue, BEAD characterizes the impact of the mitigations on this grower as “moderate-high”.

Grower 6: Southern Sweet Corn Grower. High Impact

Scenario: Florida grower. Non-irrigated sweet corn, conventional tillage. Atrazine normally applied once prior to crop emergence and once after crop emergence, at a rate of 1lbs a.i./acre both times. Ground applications.

Per label information, field is in a lower concentration watershed (List 1) on highly erodible land.

Based on a potential label Grower 6 will need to comply with the following mitigation requirements:

- Soil saturation prohibition
- Aerial application prohibition
- Precipitation restriction
- Do not apply more than 2.0 lb ai/A per year.
- At an application of 1.0 lb ai/A/y or less, **one** runoff reduction practice must be present from **Table C.**
- At an application above 1.0 lb ai/A/y, **two** runoff reduction practices must be present from **Table C.**

As Grower 6 is applying 2.0lbs ai/A/y they have to choose one of the following:

- Continue using 1 lb ai/acre preemergence and 1 lb ai/acre postemergence and adopt two runoff reduction practices.
- Continue to use a preemergence and postemergence application and reduce rates within each application to equal to 1.0lbs ai/acre per year (e.g. 0.5 lbs ai/acre preemergence and 0.5 lbs ai/acre postemergence) and adopt one runoff reduction practice.
- Maintain current application rate (1.0 lb ai/acre) and remove either the preemergence or postemergence application, facing cost increases of up to $25/A (Tindall and Kells, 2019), and adopt one runoff reduction practice.

In this hypothetical, Grower 6 will likely not be able to reduce their rate by 50% while retaining an effective rate and will therefore likely remove either the preemergence or postemergence application. BEAD expects that Grower 6 will replace the preemergence atrazine application with another herbicide but retain the postemergence atrazine application. This may increase herbicide control costs by up to $25/A, equivalent to a 61% decrease in net operating revenues (Tindall and Kells, 2019). Grower 6 may also adopt grassed waterways or a vegetative filter strip, increasing grower cost and taking land out of production. If the cost to Grower 6 of adopting runoff reduction practice outweighs the benefit of atrazine to the grower, Grower 6 will switch from using atrazine to using alternative herbicides. Because Grower 6 has to replace one atrazine application, facing substantial in net revenue, and also adopt a new mitigation practice, BEAD concludes this grower will face a high impact.

NB: This same grower would have faced only low impact if they had been on non-highly erodible soil or if they were only using atrazine once.

Grower 7: Florida Sugarcane Grower. Low Impact

Scenario: Florida grower. Sugarcane. Grower has a vegetative ditch bank, as is typical for the region. Atrazine normally applied twice per year, at a rate of 3-4lbs a.i./acre both times, as is typical for the region. Ground applications.

Based on a potential label Grower 7 will need to comply with the following mitigation requirements:

- Soil saturation prohibition
- Aerial application prohibition
- Precipitation restriction
- Do not apply more than 8 lbs ai/A/yr
- Must use a vegetative ditch bank

Because this grower already meets the standards for use of atrazine, BEAD expects Grower 7 will not be impacted by these mitigations. BEAD concludes that the mitigations will have low impact on Grower 7.